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Beyens et al.

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(54) **SAMPLER FOR HOT METAL**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 195 days.

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This patent is subject to a terminal disclaimer.

European Patent Search Report issued in EP Application No. 16203822.8 dated Aug. 14, 2017.

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Primary Examiner — Nathaniel J Kolb

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(57) **ABSTRACT**

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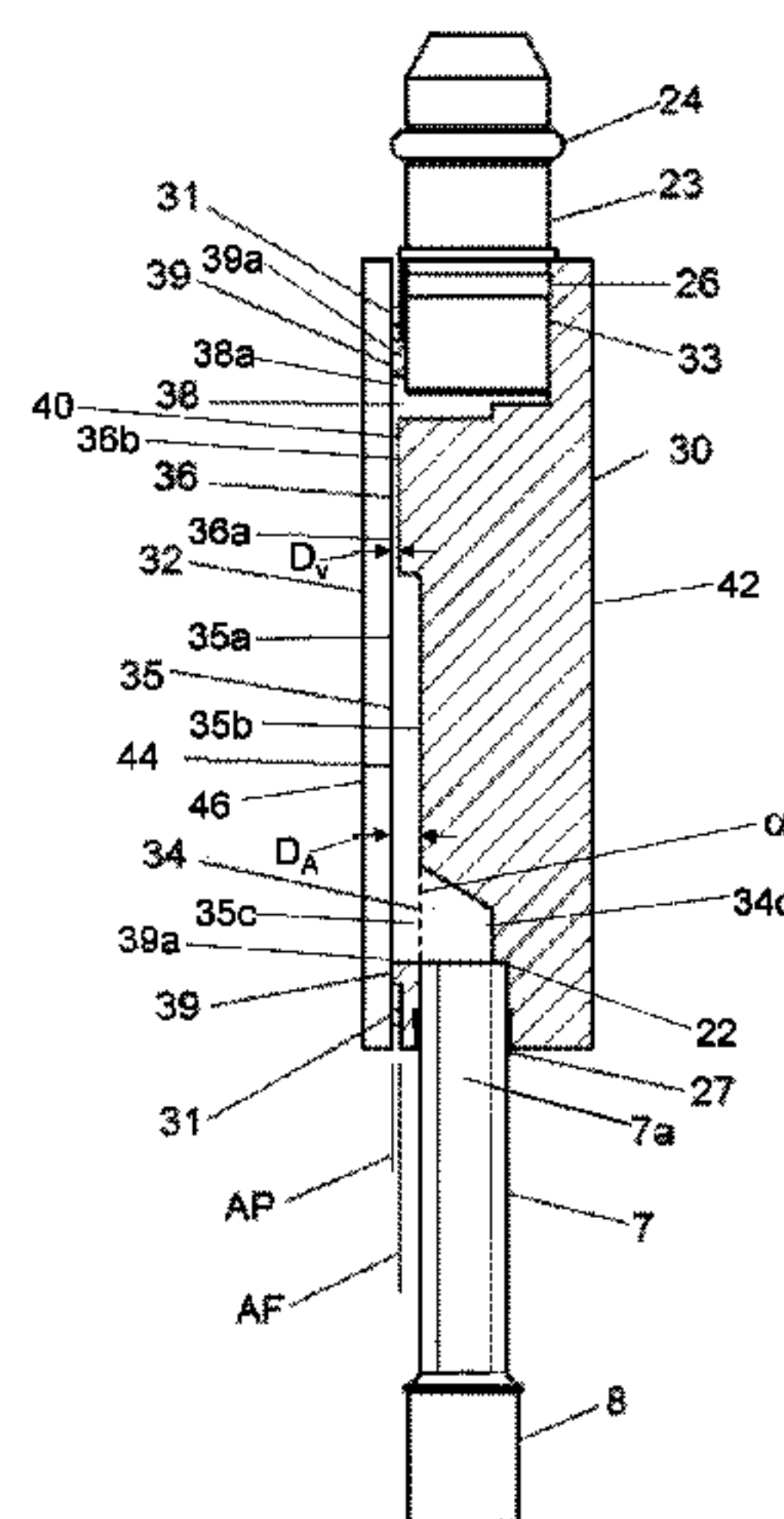
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A sampler for taking samples from a molten metal bath, particularly a molten iron includes a sample chamber assembly having a cover plate and a housing. The housing has first and second openings for an inflow conduit and a gas coupler, respectively. The first face has an analysis zone, a ventilation zone, and a distribution zone. A depth of the analysis zone is 0.5 mm to 1.5 mm. The cover plate and the housing are assembled together to form a sample cavity. The sample chamber assembly chills the molten iron received therein to a solidified white structure metal sample. An analysis surface of the sample lies in a first plane. In a flow direction of the molten iron, there are no increases in width of the sample cavity and a ratio of the length to depth of the sample cavity increases.

19 Claims, 10 Drawing Sheets



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- (52) **U.S. Cl.**
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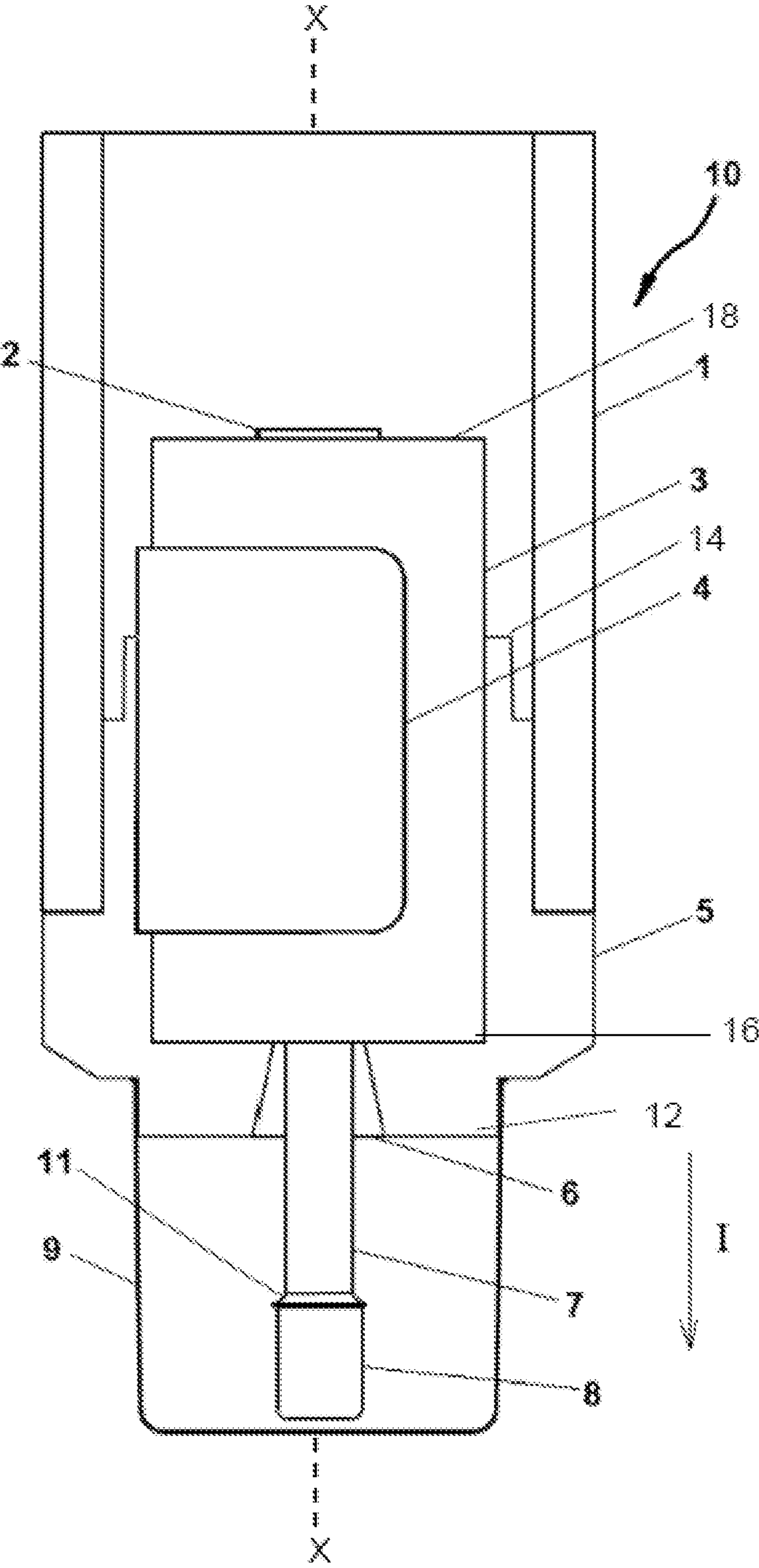


Fig. 1

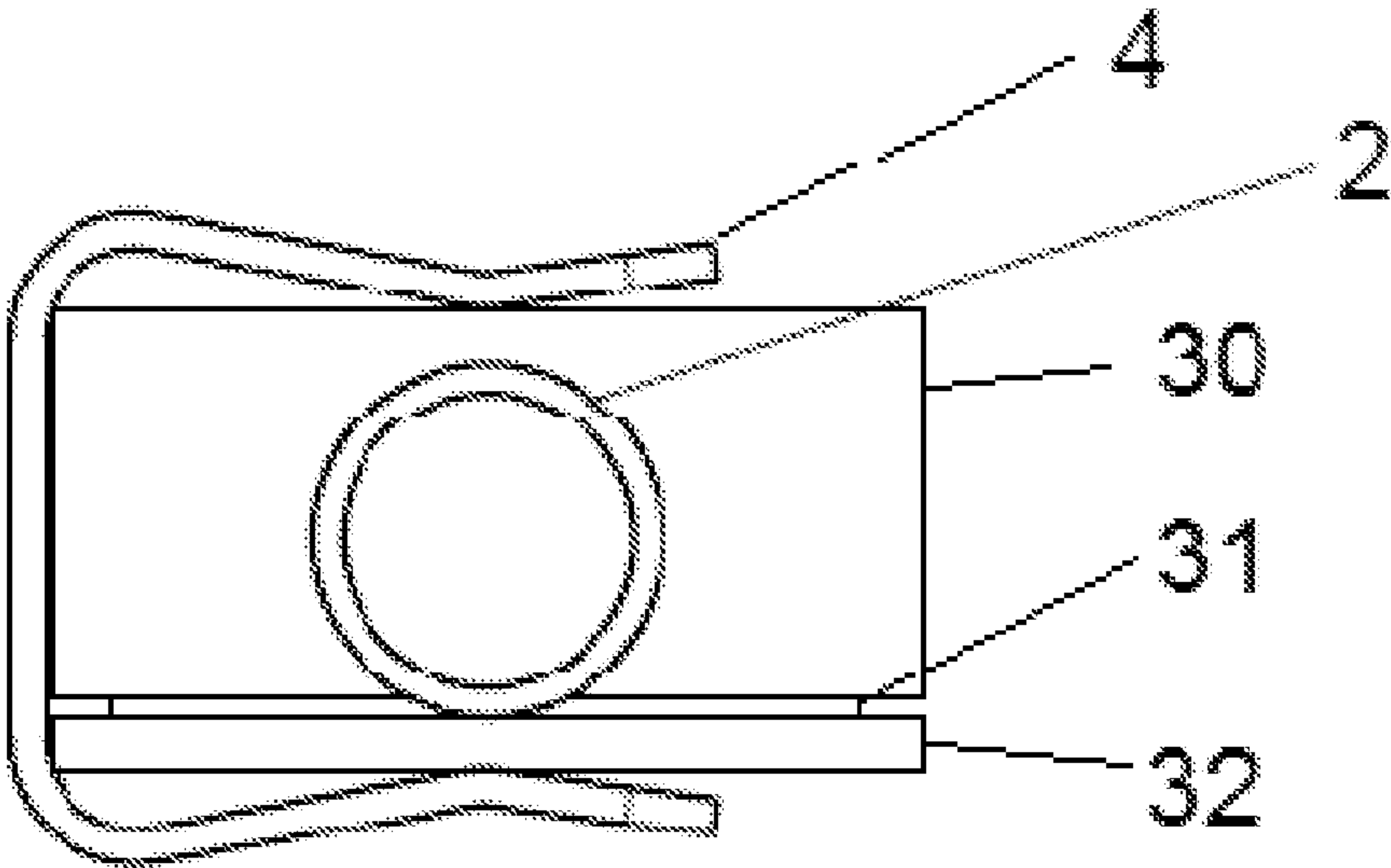


FIG. 2

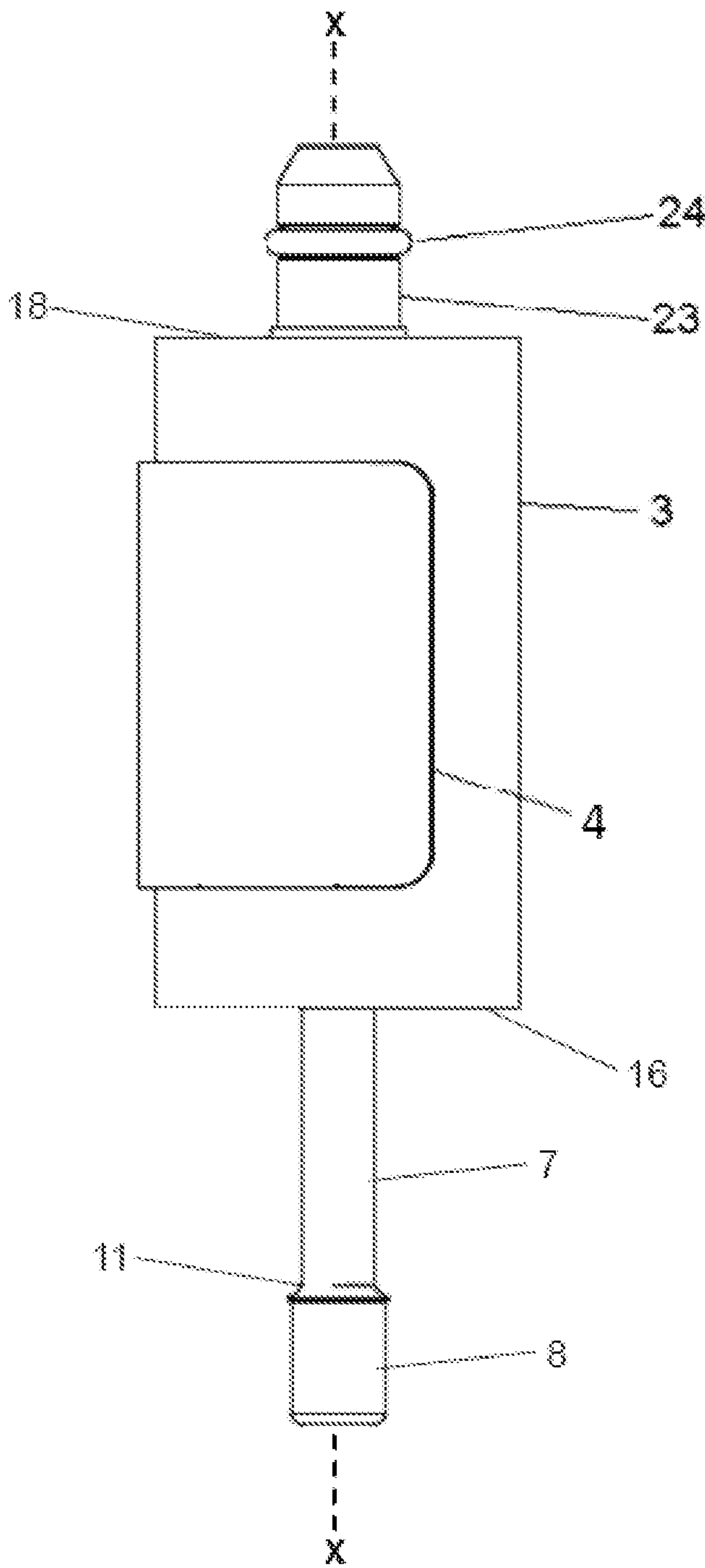


FIG. 3

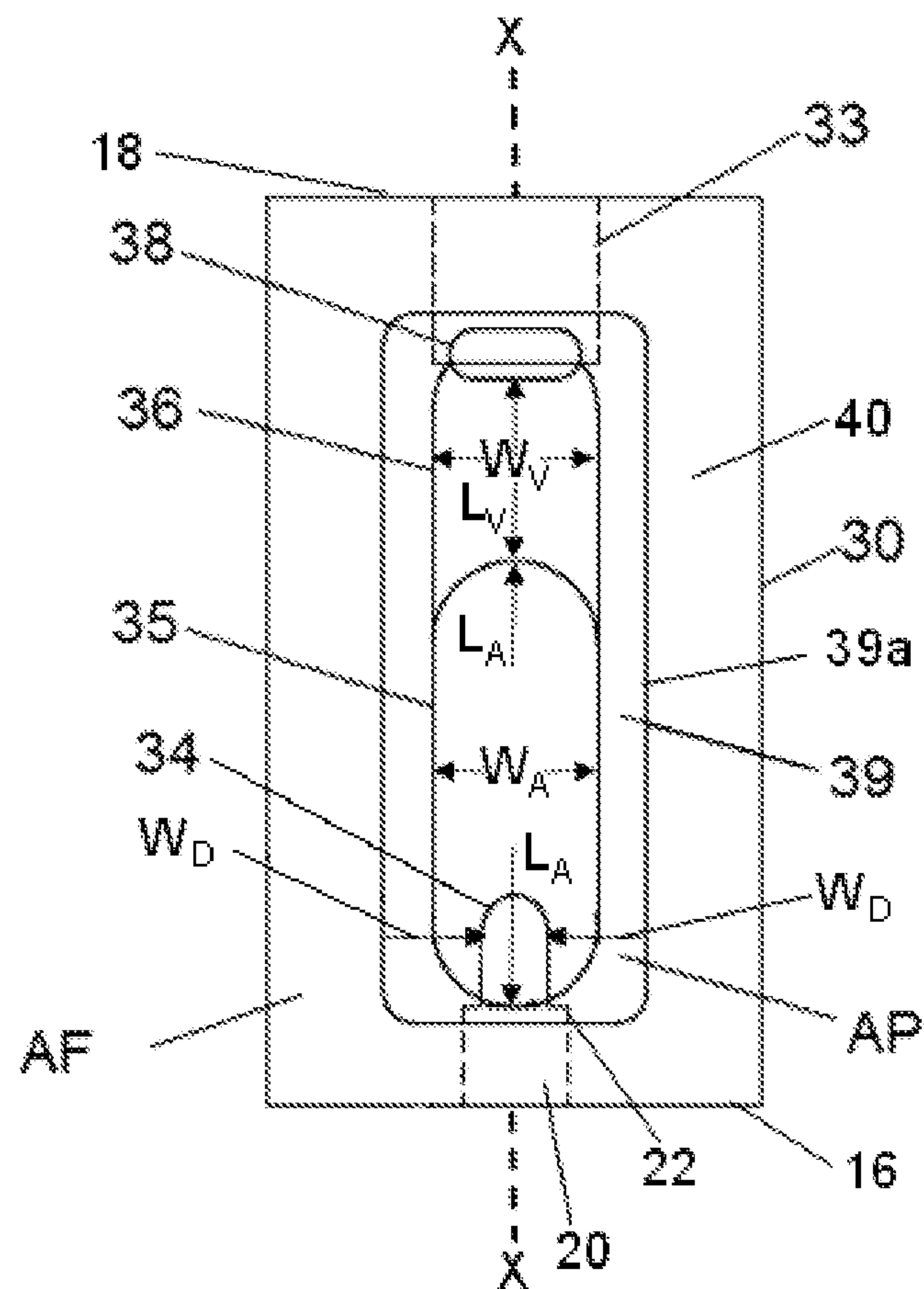


Fig. 4

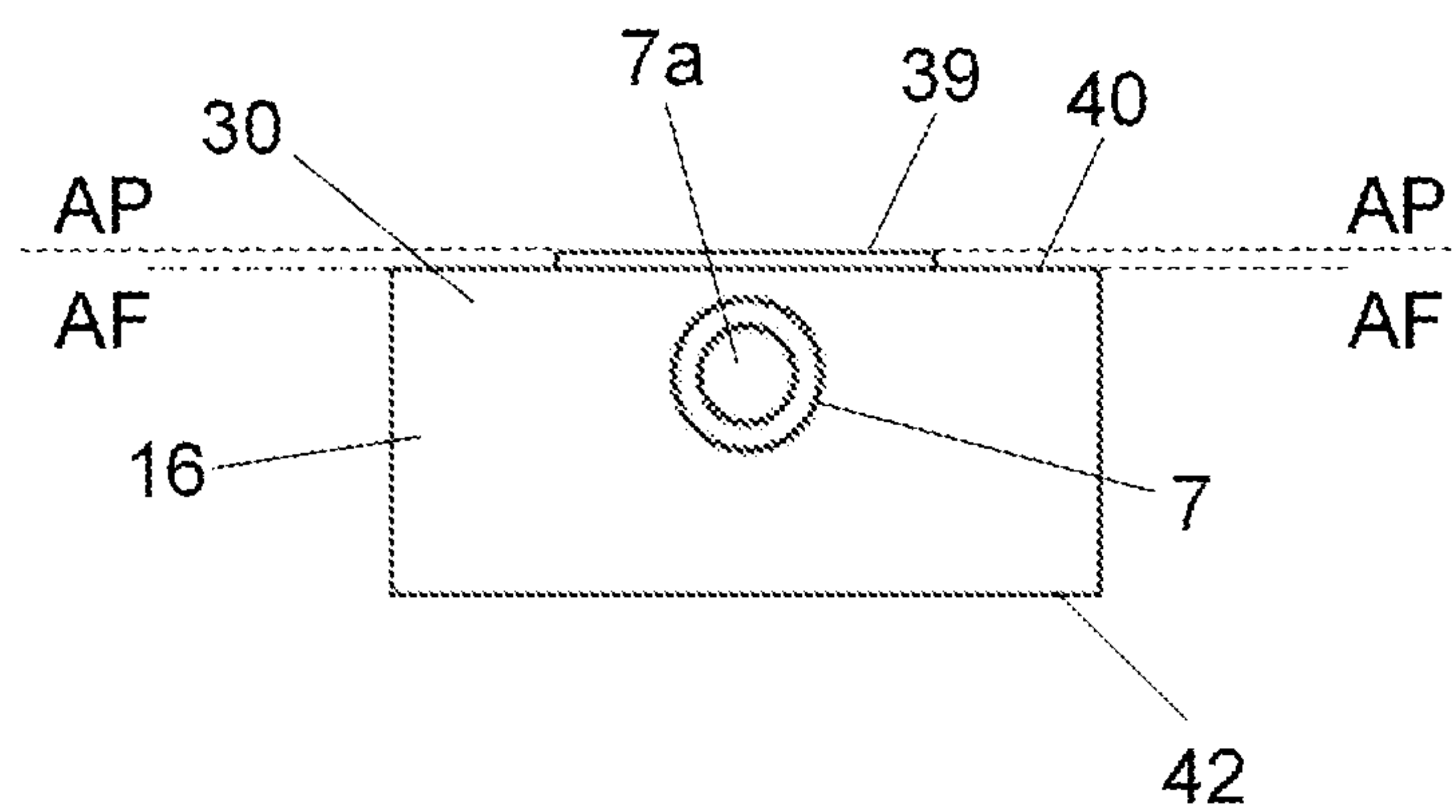


Fig. 4A

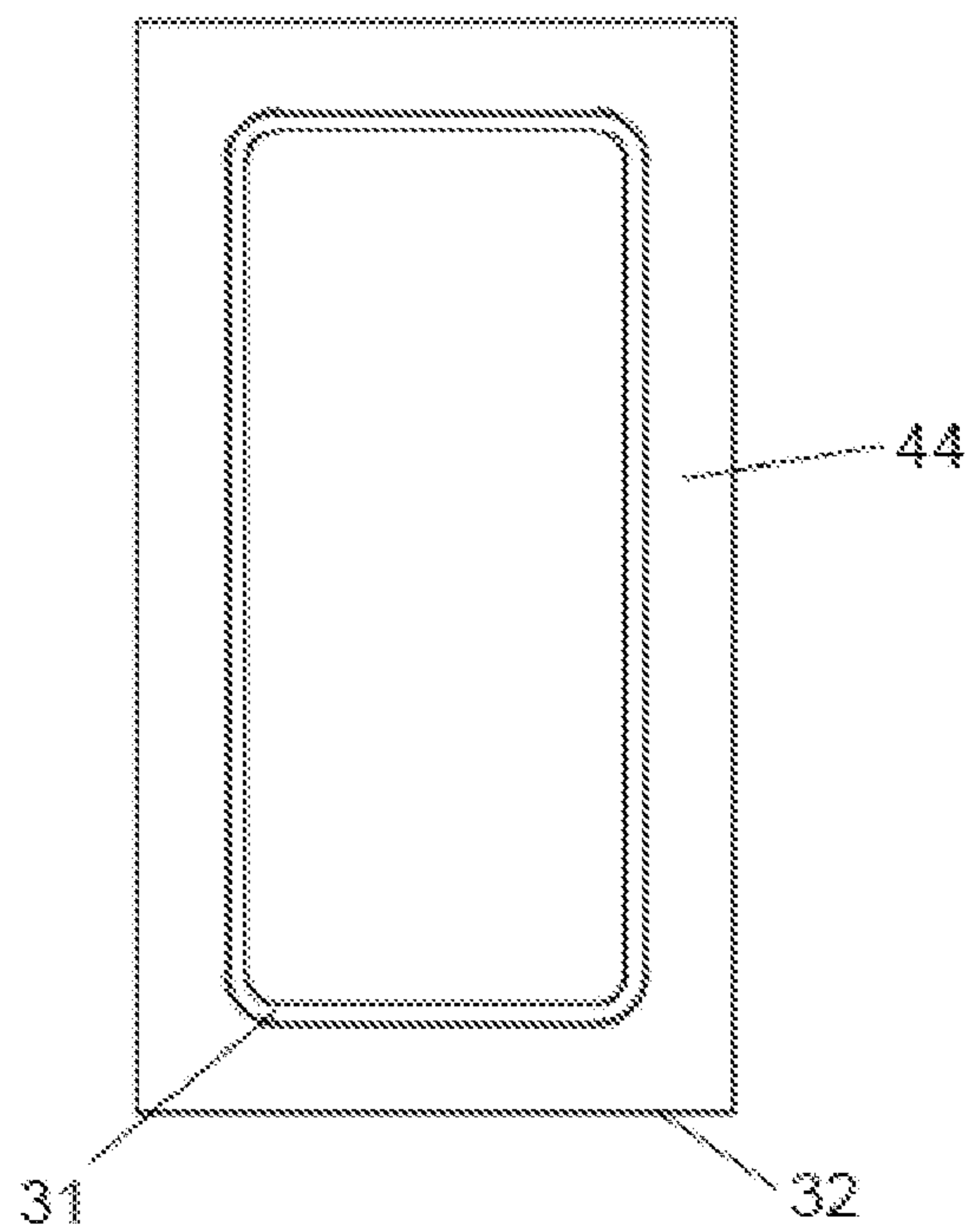


FIG. 5

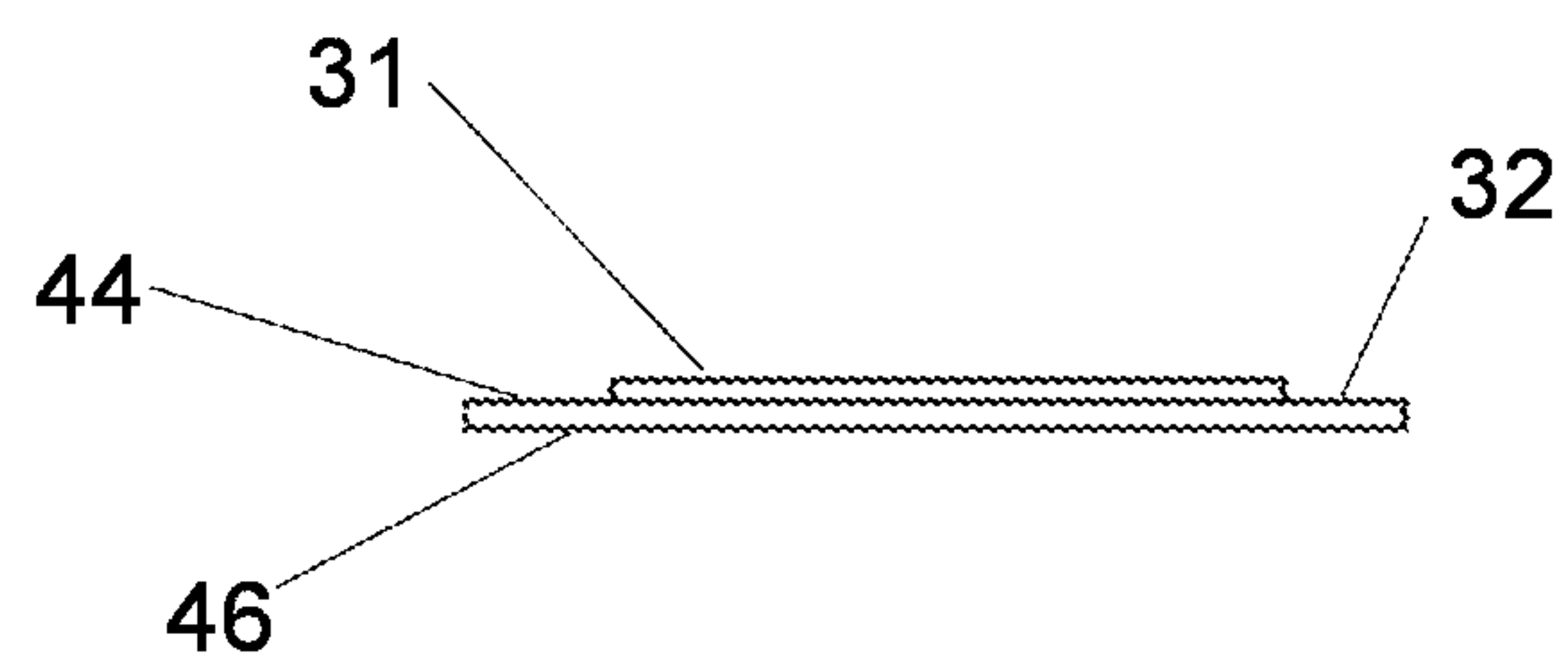


FIG. 5A

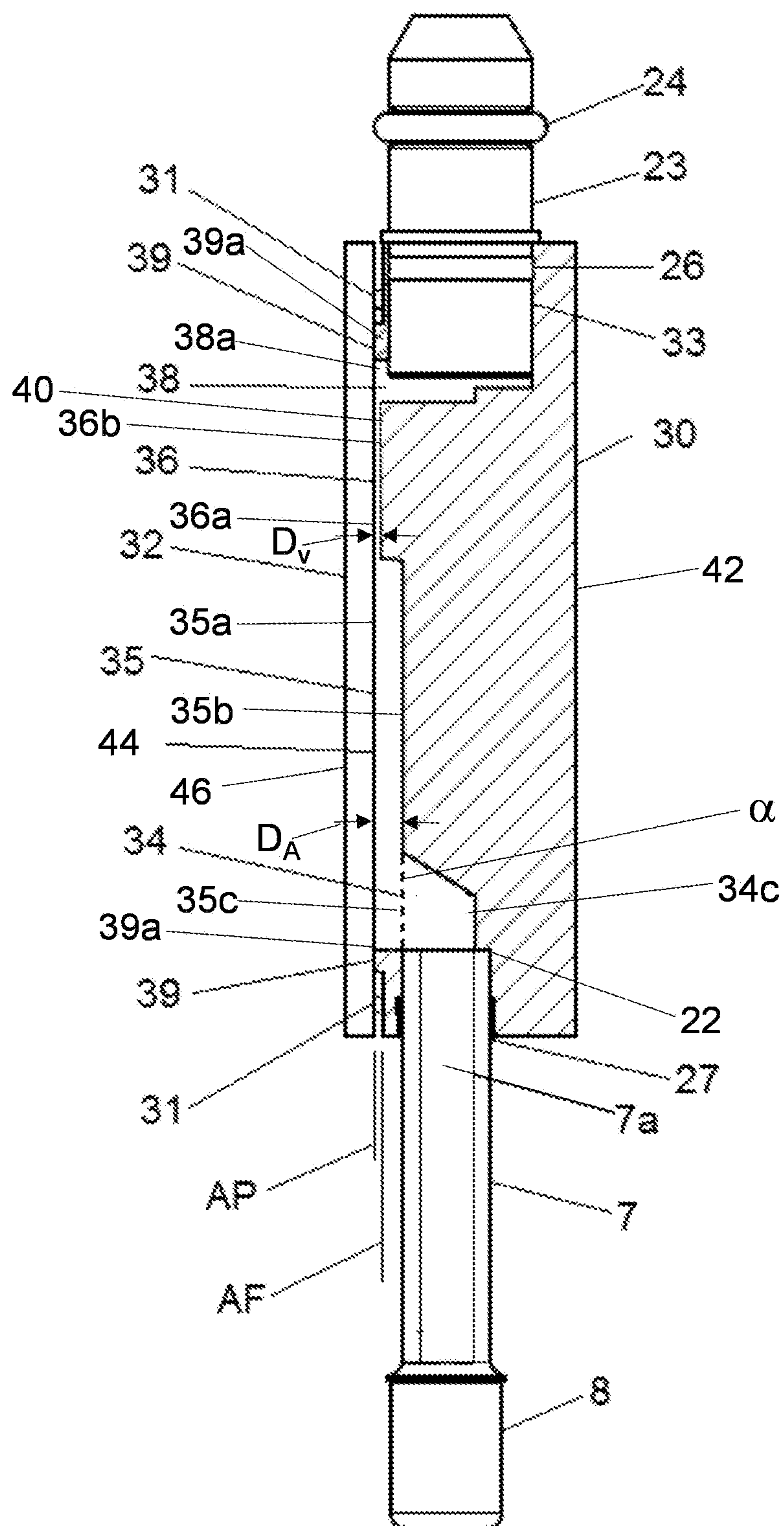


FIG. 6

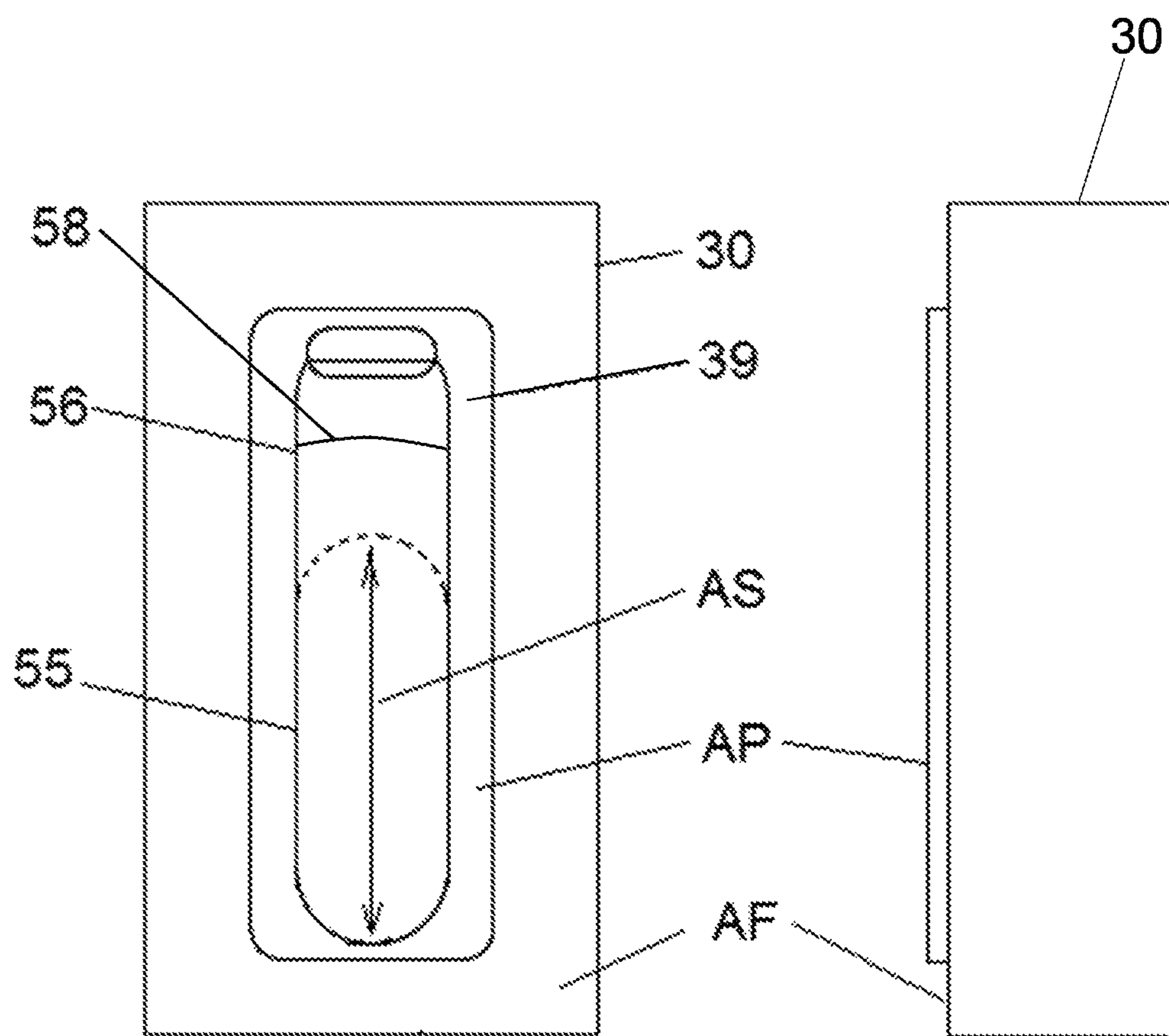


FIG. 7

FIG. 7A

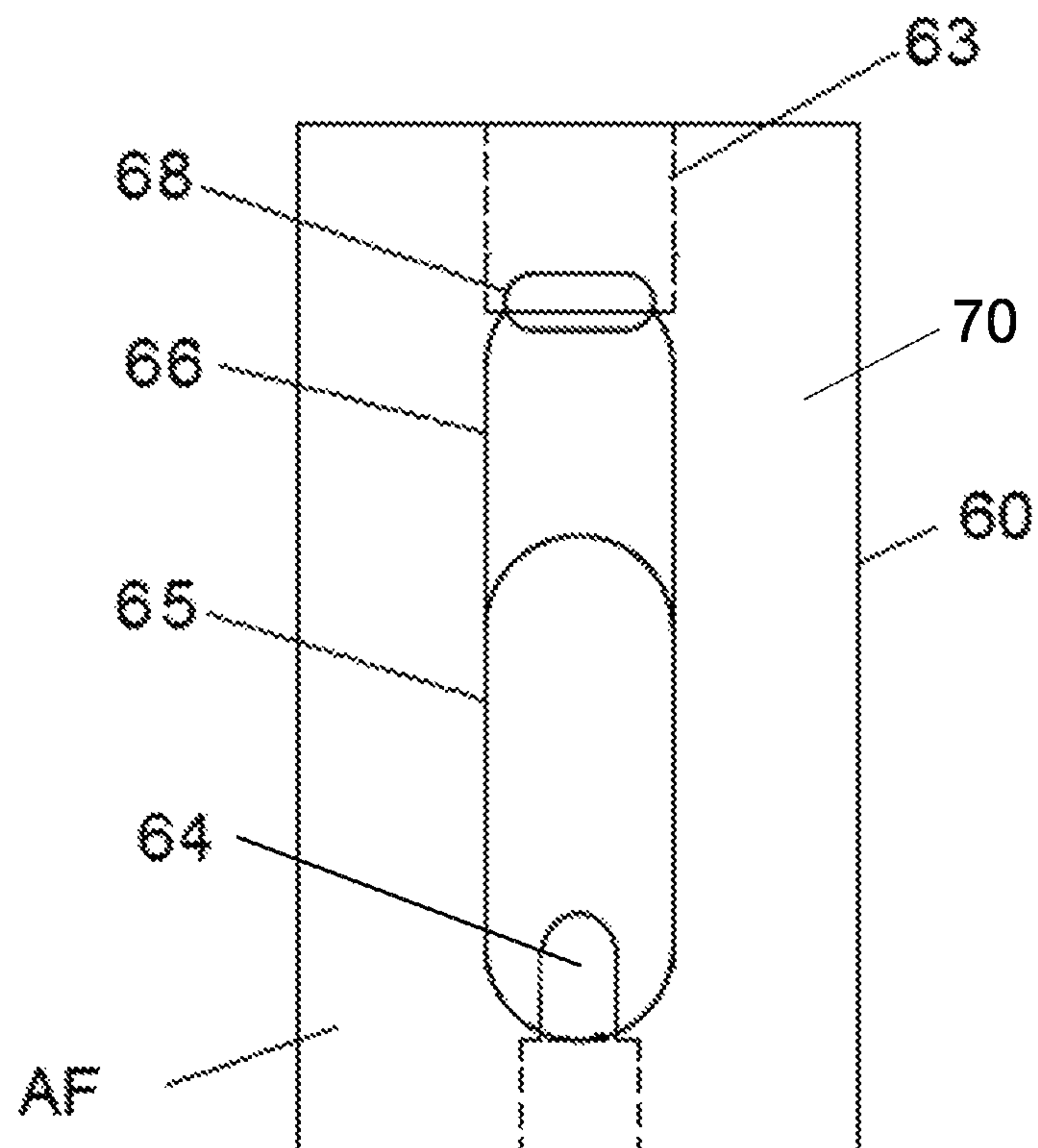


FIG. 8

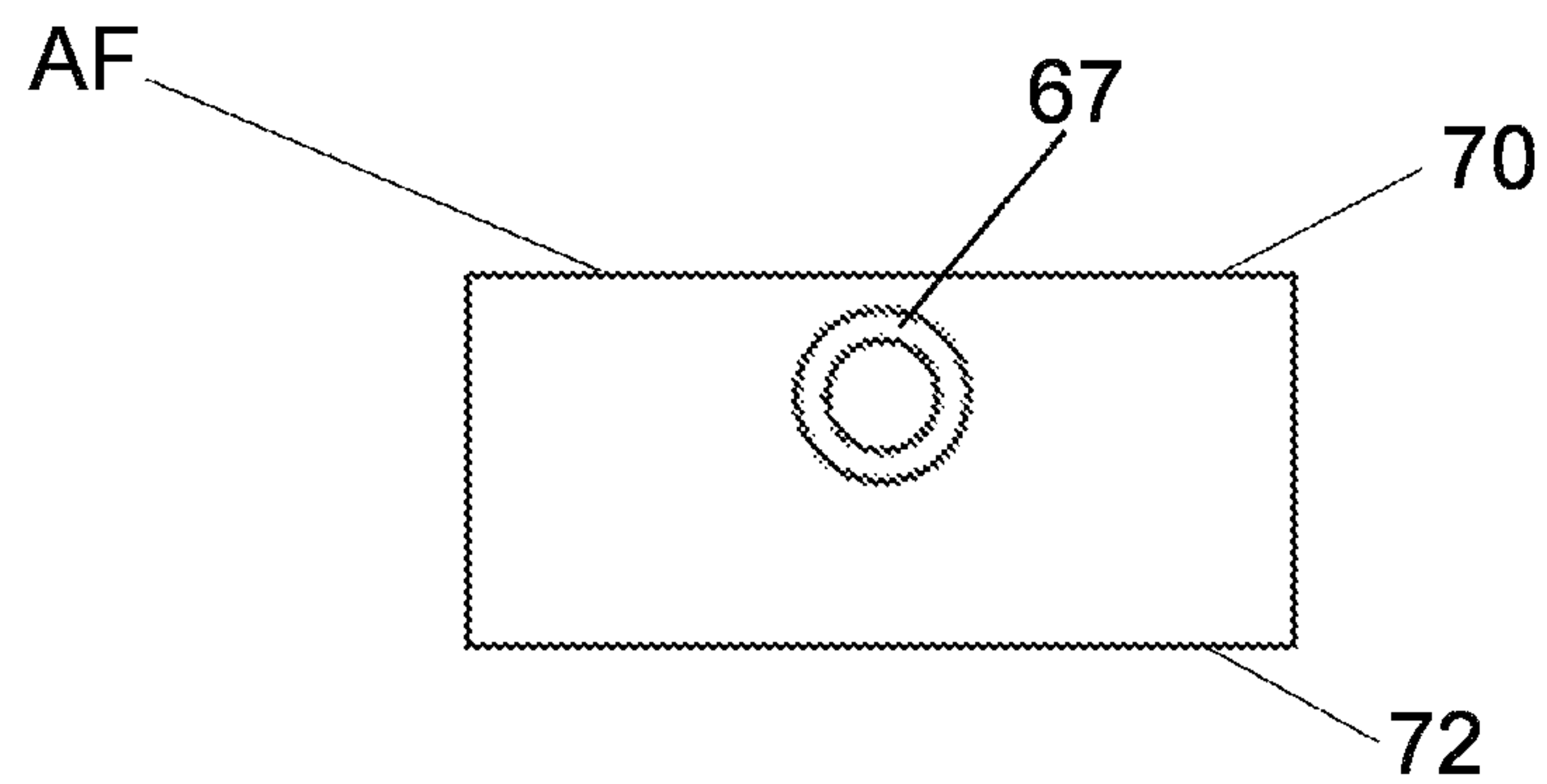


FIG. 8A

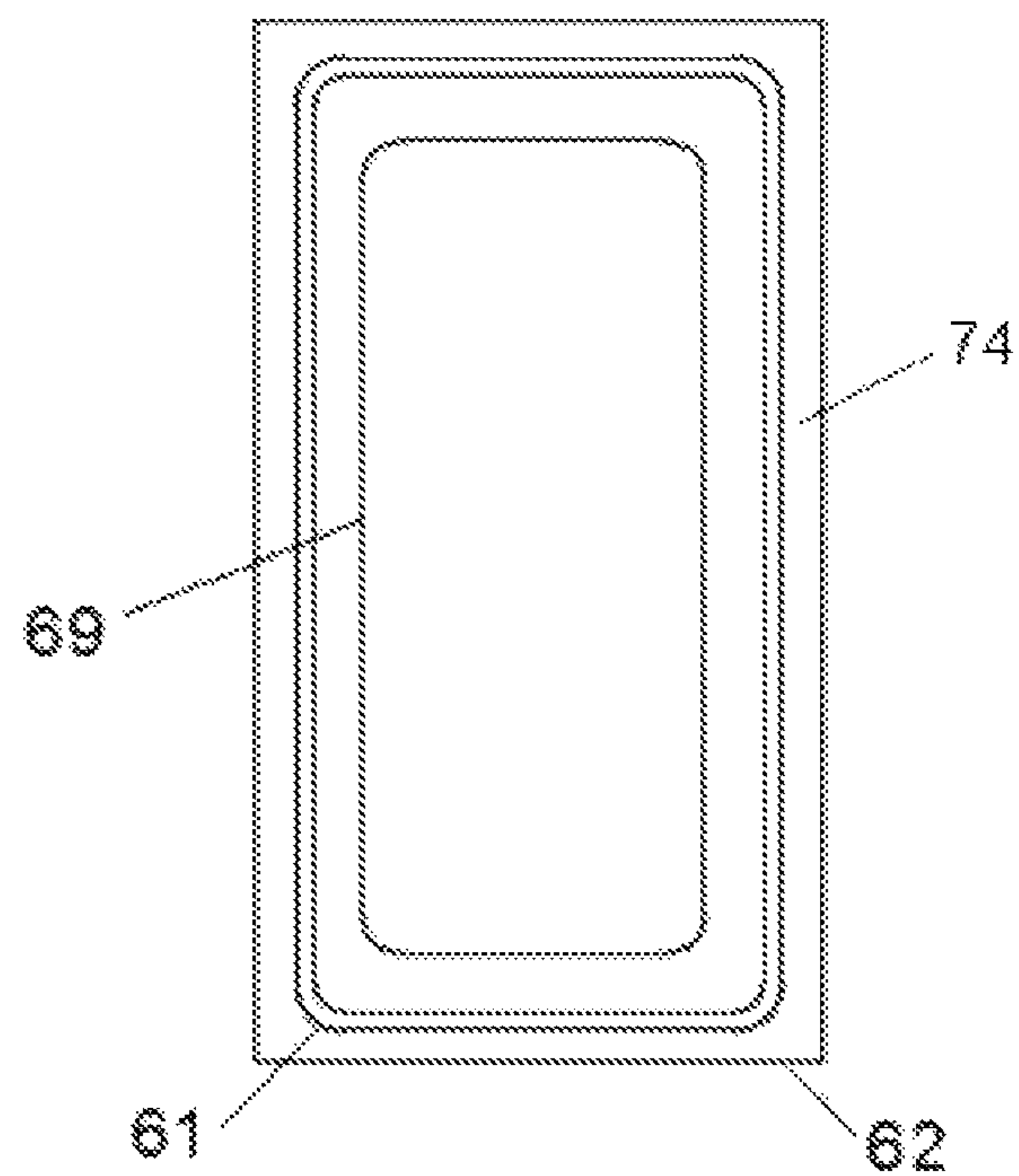


FIG. 9



FIG. 9A

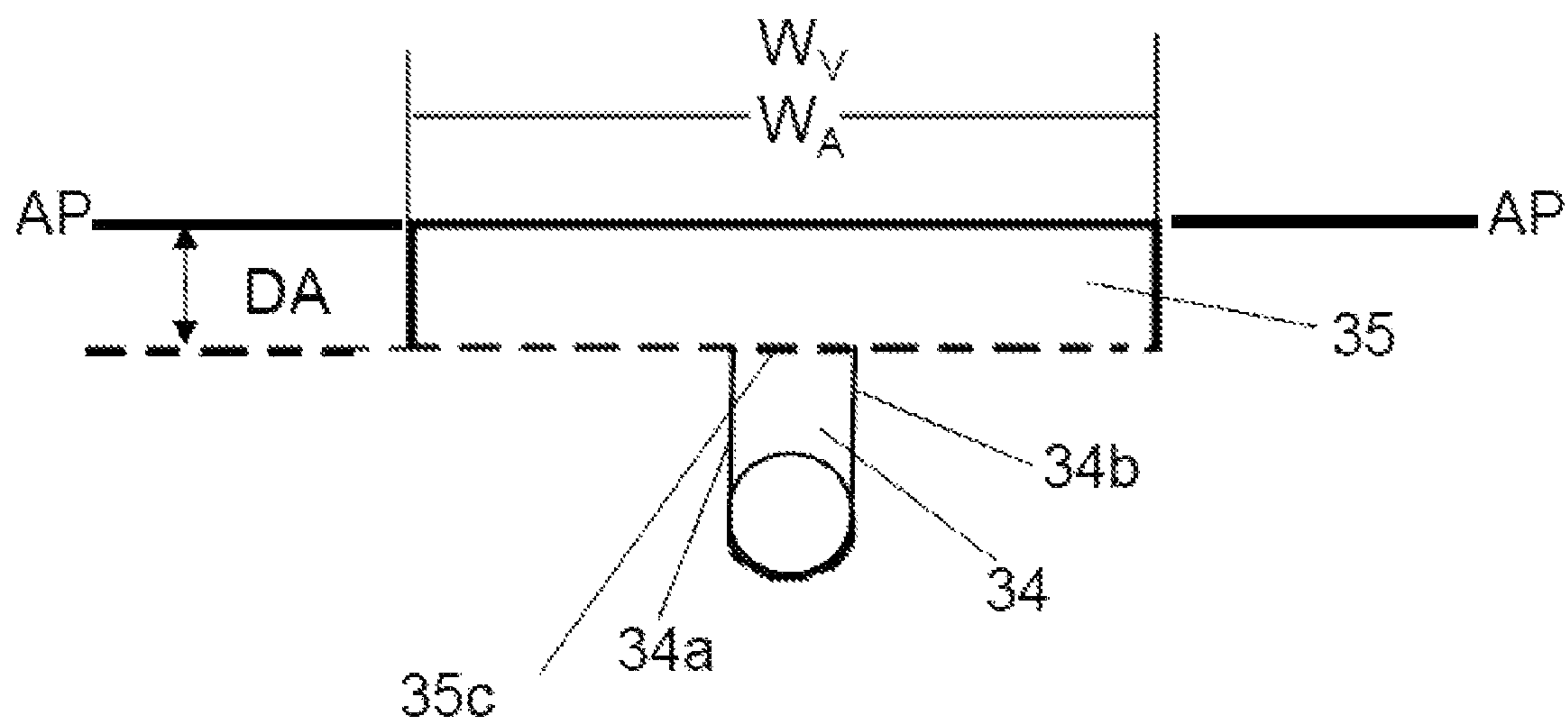


FIG. 10

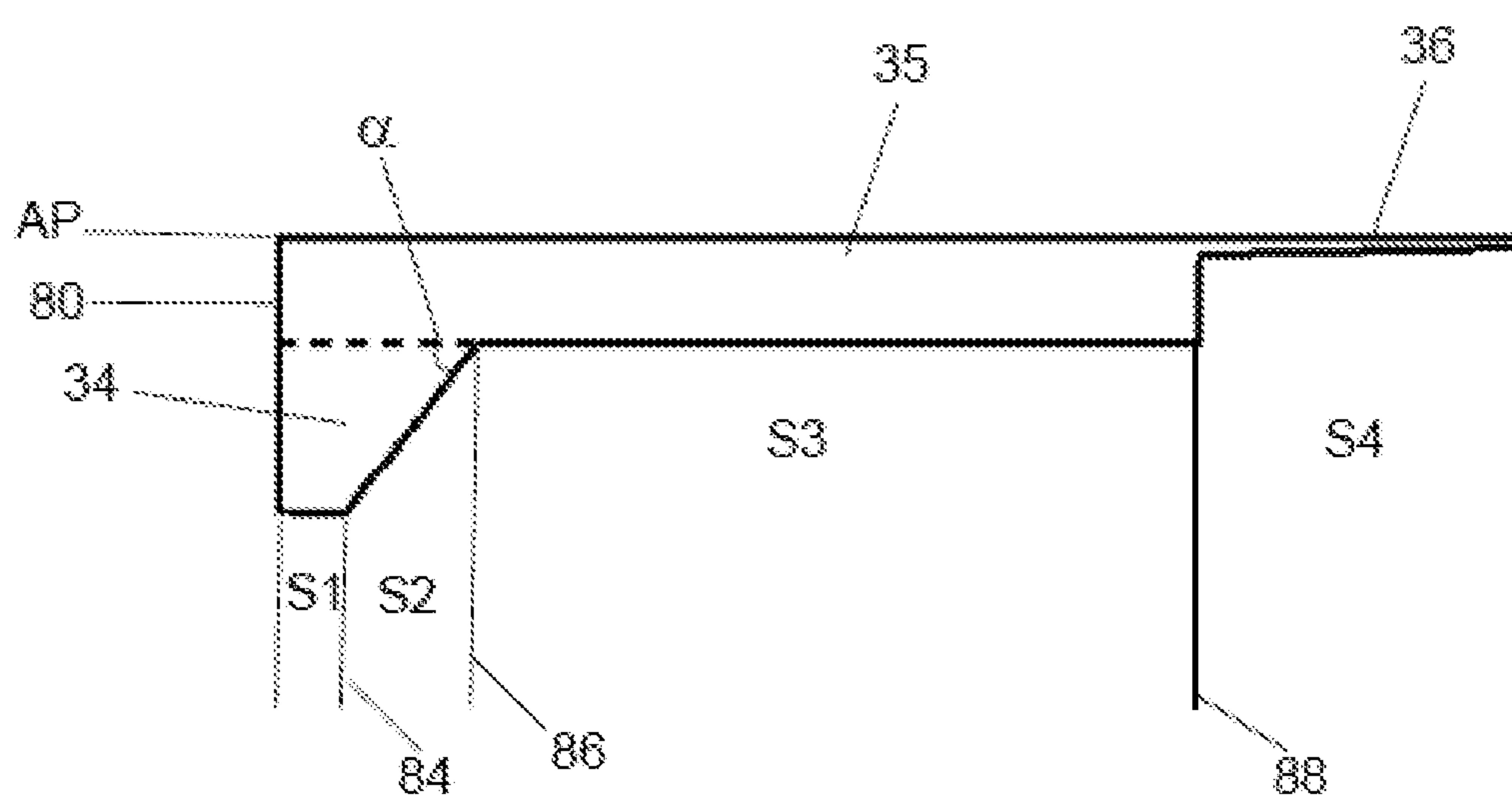


FIG. 11

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SAMPLER FOR HOT METAL

CROSS REFERENCE TO RELATED
APPLICATION

This application claims the benefit of EP Application No. 16203822.8, filed Dec. 13, 2016, the contents of which are incorporated by reference herein in its entirety.

TECHNICAL FIELD

The invention relates to a crack-free solidified sample of hot metal, particularly molten iron of a high carbon content, which can be directly analyzed on an optical emission spectrometer. The invention also relates to the physical arrangement of a hot metal immersion sampling device for retrieving a molten sample capable of quick chilling to produce a coupon of metal suitable for rapid and robotic assisted analysis without cracks and without surface preparation.

BACKGROUND OF THE DISCLOSURE

During the metallurgical processing of steel, molten iron, commonly known as hot metal, obtained from the blast furnace is used as a raw material feed into the subsequent steelmaking process carried out in a converter. Although obtained in batch quantities from the blast furnace, the hot metal is sometimes mixed with other iron batches or treated to alter its chemistry prior to being charged into the converter. Accordingly, it is advantageous to extract a sample of the hot metal, in order to determine its chemical composition during treatment and for use in mass and energy balances of the converter process. Devices for extracting samples of hot metal for chemical analysis are well known in the art. An example of one such prior art reference is U.S. Pat. No. 3,996,803.

The chemical laboratory of a steelworks has a variety of analytical equipment to determine the elemental composition of metal samples. The most widely used process to analyze metal samples is by optical emission spectroscopy, hereinafter called OES. Due to their rapid analysis time and inherent accuracy, OES systems are the most effective systems for determining the chemical composition of a metal sample and for controlling the processing of molten metals. However, samples obtained of blast furnace hot metal containing high concentrations of carbon and silicon are typically analyzed by X-ray fluorescence spectroscopy, rather than by OES.

The choice of analytic equipment other than OES for use with hot metal samples is dictated by the metallographic structure of the extracted sample. Typically, a hot metal sampler is a low cost sampling device mounted on a carrier tube and having a side inlet for the hot metal to enter a sampling chamber that is formed by two thick metal chill plates. The sample can easily be retrieved by crushing the sandbody surrounding the sampling chamber, after withdrawal of the sampler device from the hot melt. The hot metal instantly solidifies as it enters the sampling chamber. During solidification, gas bubbles and unwanted inclusions will rise to the top of the sample, and thus the bottom side of the solidified sample is used for analysis. The rapid cooling results in a consistently chilled sample, thereby meeting all specifications for a reliable analysis with optical spectrometers.

Hot metal samplers known in the art typically provide 35 mm round coin samples with thicknesses varying from 4

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mm to 12 mm, optionally with a pin of 4 mm or 6 mm for combustion analysis. It is known from the art that during cooling to a solid, the molten sample can undergo a multitude of precipitation reactions, thereby resulting in different solidification structures due to the chemical composition of the iron and the rate of cooling the liquid metal to its solidification temperature. Since the bath temperature at the time of sampling may range from 1250° C. to 1500° C., a single prior art sampling device could result in different solidification structures.

The dominant solidification structures receive their names from the appearance of the fracture surface due to the form of carbon in the as-cast metal.

Specifically, for high carbon irons, at or above the eutectic composition, carbon will precipitate out of solution during cooling in the form of graphite flakes, thereby giving rise to its appearance and name, grey iron. In iron compositions less than the eutectic composition, grey iron can still be produced when the metal contains graphite. Promoters (e.g., elements such as silicon and phosphorus), when present in appropriate compositions such as that of blast furnace iron, are used to influence solidification towards a grey iron structure. Grey iron is not suitable for analysis on an optical emission spectrometer.

Another solidification structure occurs during rapid cooling of the iron, where dissolved carbon precipitates as white or chilled iron as a result of its shiny silver appearance. White or chill iron occurs when cast iron solidifies by precipitation of the iron carbide/austenite eutectic. For a white structure to form, the dominant grey iron eutectic must be suppressed by undercooling to a temperature below the white iron eutectic. The extent of such cooling must be such that the white iron eutectic composition is nucleated and grows in preference to the grey iron eutectic. When the suppression by chilling is slightly insufficient or occurs too late, such that graphite precipitation has already begun, the metal will chill with a white structure but interspersed with graphite. This is termed mottle iron, meaning it is neither grey nor white. The characteristics of mottle iron vary depending upon the rate of early cooling and the degree of inoculation. Analysis of this type of iron structure produces inaccurate results depending upon the location point of the analysis and its proximity to the chill surface.

U.S. Pat. No. 3,406,736 describes a device where additives are used to avoid mottle. However, inoculation is a process which results from additives to the metal which are difficult to uniformly achieve in immersion sampling devices and do result in elements added to the sample that were not present in the initial hot metal.

In order to promote white solidification in a hot metal sampling device without the use of additives, high mass and/or high conductivity solid metals must be used to form the molds into which the hot metal is cast, thereby providing the necessary chill. Surprising results have been obtained from very high solidification rate sampling devices, called direct analysis (DA) samplers. These results demonstrate that a pure white iron structure can be routinely obtained from blast furnace iron containing graphite-promoting elements, cooled from as high as 1525° C., and accurately analyzed by an optical emission spectrometer.

Broadly speaking, the OES analysis procedure begins with the conductive metal sample being positioned with its analysis surface face down on a predetermined region of the stage of the OES instrument, namely an optical emission spectrometer. More particularly, the sample is positioned so as to span and close the analysis opening of the spectrometer and an anode nearly abuts the analysis surface of the sample.

Once the desired positioning of the sample and proximity of the anode and analysis surface is achieved, a spark is discharged between the anode and the conductive metal sample which is electrically connected to the spectrometer stage. This connection is, in most cases, made by gravitational force in combination with a small load. The analysis opening on the optical emission spectrometer is typically around 12 mm wide. This distance avoids that a spark arcs between the anode and the instrument housing. The optical detector receives the emitted light from the excavated material of the sample surface. The spark chamber, formed in part by the space between the anode and the metal sample, is continuously purged with argon or other inert gas in order to avoid air ingress which would lead to erroneous analysis values.

In order to lay flat across the analysis opening of the spectrometer, the metal sample cannot have any extensions and the analysis surface of the metal sample must be smooth (i.e., of there can be no parts of the sample housing which break the plane of the analysis surface). The sample must span the analysis opening of the spectrometer and be of sufficient flatness to facilitate inert gas purging of the spark chamber and present a contiguous sample surface toward the anode.

Direct Analysis (DA) samplers are a newly developed type of molten metal immersion sampler which produce DA samples. DA samples do not require any kind of surface preparation before being analyzed, and thus can result in significant economic benefit both in terms of the availability of timely chemistry results as well as laboratory time savings by utilizing the OES analysis method.

U.S. Pat. No. 9,128,013 discloses a sampling device for collecting a DA type sample from a molten steel bath. The sampling device includes a sample chamber formed by at least two parts. A similar DA type sampler is known from U.S. Patent Application Publication No. 2014/318276. One end of the sample cavity of this DA type sampler is connected to the molten metal bath during immersion of the sampler via an inflow conduit, while an opposite end of the sample cavity is in communication with a coupling device. During immersion, but before the filling of the sample cavity with the molten metal, the sample cavity is purged with an inert gas to avoid early filling and oxidation of the sampled material. The inflow conduit is arranged perpendicular to the flat surface of the sample cavity. The ventilation of the sample cavity is arranged below the analysis surface of the sample cavity relative to the immersion direction.

While such conventional sampling devices may be adequate for retrieving steel samples suitable for preparation free OES analysis, it has been determined that the necessary cooling rate required to result in a pure white solidification structure from hot metal containing graphitization elements results in cracking along the surface of the resulting sample, as well as cracking which spans the thickness of the resulting sample. This is problematic because an excitation spark of the OES, when incident upon a cracked surface, will produce erroneous results. Also, the metal sample to be analyzed by OES is placed with the analysis surface downward. In the most extreme cases, cracking can result in pieces of metal dislodging from the body of the sample and falling into the OES sparking area. Robotic equipment in a typical steelworks laboratory is ill equipped to handle this type of equipment contamination.

Also, samples produced by conventional sampling devices have a diameter of at least 32 mm in a direction parallel to the spectrometer opening and a thickness of 4-12 mm in a direction perpendicular to the spectrometer open-

ing. Such dimensions can be easily handled by pre-analysis preparation equipment that mechanically grinds the analysis surface of the metal sample to clean oxides from the surface and provide the requisite flat topography. This geometry is also convenient to robotic manipulators which advance the sample from preparation through analysis and removal to await the next sample. Robotic equipment in a typical steelworks laboratory is difficult to modify to accept radically different sample geometries.

However, the prior art sample volume is over dimensioned from the minimum volume of metal required to arrive at the minimum necessary analyzed surface area. The sample volumes of the prior art devices thus preclude rapid solidification of the molten metal sample, which is necessary to obtain an oxide free surface. As such, conventional devices cannot be reliably analyzed by OES without surface preparation. Using massive cooling plates and sampler housings to force a large volume metal sample to low temperature after retrieval becomes impractical for rapid de-molding and is uneconomical for use as immersion sampling devices.

Accordingly, it would be beneficial to provide a DA type sample for OES analysis capable of being used for sampling hot metal and forming a solidified hot metal sample without cracking. It would be beneficial to provide a DA type sampler which produces preparation free samples of hot metal that are capable of being subjected to the degree of rapid chill necessary to promote a pure white solidification structure (i.e., a structure without graphite precipitation) and which remain crack-free, and are thus suitable for analysis by OES.

It would also be beneficial to provide a molten metal immersion device for retrieving preparation free samples from a hot metal within metallurgical vessels which is capable of quick connection to pneumatic-assisted inert gas purge apparatus and exhibits reduced pressure metal uptake. In particular, it would be beneficial to provide a molten metal immersion device for producing a molten metal sample that is easily obtained and quickly removed from the immersion device housing, de-molded from the sample chamber, and directly analyzed on the OES without additional cooling or preparation, and which is thereby cost-effective.

SUMMARY OF THE INVENTION

The invention relates to a rapid chilled sampler which is filled with hot metal in the immersion direction parallel to the longitudinal axis and which produces a locally analyzed white structure hot metal sample. This configuration, as described in more detailed herein, provides the greatest utility on existing optical emission spectrographs which, at present, require an analyzable surface to be of certain dimensions, and also provides an optimum geometry fitting into the aforementioned carrier tubes in order to remove and de-mold the metal sample with minimal effort.

In summary, the following embodiments are proposed as particularly preferred in the scope of the invention:

Embodiment 1

A sampler for taking samples from a molten metal bath, particularly a molten iron, the sampler comprising:
a carrier tube having an immersion end;
a sample chamber assembly arranged on the immersion end of the carrier tube, the sample chamber assembly comprising a cover plate and a housing, characterized in that the housing includes:

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an immersion end having a first opening for an inflow conduit and an opposing end having a second opening for a gas coupler; and

a first face extending between the immersion end and the opposing end, the first face having a first depression proximate the immersion end and a second depression, the first depression being an analysis zone and the second depression being a ventilation zone, a portion of the analysis zone overlying a distribution zone which is in direct flow communication with the first opening and configured to receive the molten iron from the inflow conduit,

wherein a depth of the analysis zone is 0.5 mm to 1.5 mm,

wherein the cover plate and the housing are configured to be assembled together to form a sample cavity including the distribution zone, the analysis zone and the ventilation zone,

wherein the assembled cover plate and housing are configured to chill the molten iron received therein to a solidified white structure metal sample, such that an analysis surface of the solidified white structure metal sample lies in a first plane, and

wherein the first and second openings are spaced apart from the first plane.

Embodiment 2

A sampler according to the preceding embodiment, in that the sample cavity and the first and second openings are aligned along a common longitudinal axis.

Embodiment 3

A sampler according to any of the preceding embodiments, characterized in that the analysis zone, distribution zone and ventilation zone are structured as a plurality of contiguous segments, each segment having a length to depth ratio, a sum of the length to depth ratios of the plurality of segments being greater than 25.

Embodiment 4

A sampler according to any of the preceding embodiments, characterized in that the distribution zone, analysis zone and ventilation zone are structured as a plurality of contiguous segments, each segment having a length to depth ratio, the length to depth ratios of the segments successively increasing as the distance from the first opening increases.

Embodiment 5

A sampler according to any of the preceding embodiments, characterized in that there are no increases in a width dimension of the sample cavity in a flow direction of the molten iron from the end of the distribution zone toward the gas coupler.

Embodiment 6

A sampler according to any of the preceding embodiments, characterized in that a total length of the analysis zone and the ventilation zone is between 20 and 50 mm, preferably 30 mm long.

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Embodiment 7

A sampler according to any of the preceding embodiments, characterized in that the analysis zone has a uniform depth above the distribution zone.

Embodiment 8

A sampler according to any of the preceding embodiments, characterized in that a cross-sectional area of at least a portion of the analysis zone gradually tapers in the flow direction of the molten iron.

Embodiment 9

A sampler according to any of the preceding embodiments, characterized in that a cross-sectional area of the ventilation zone gradually tapers in the flow direction of the molten iron.

Embodiment 10

A sampler according to any of the preceding embodiments, characterized in that a ratio of a mass of the sample chamber to a mass of the metal received within the sample collection volume is 9 to 12, preferably 10,

Embodiment 11

A sampler according to any of the preceding embodiments, characterized in that the cover plate accounts for 10 to 20 percent of the mass of the sample chamber.

Embodiment 12

A sampler according to any of the preceding embodiments, characterized in that a cross-sectional area of the inflow conduit is between 0.20 and 0.70 times of a cross-sectional area of the distribution zone, preferably 0.55.

Embodiment 13

A sampler according to any of the preceding embodiments, characterized in that a bottom surface of the distribution zone intersects a closed bottom end of the analysis zone at an angle between 40 and 90°, preferably 60°.

Embodiment 14

A sampler according to any of the preceding embodiments, characterized in that the cover plate includes a sealing member configured to provide a substantially gas tight seal between the cover plate and the housing.

Embodiment 15

A sampler according to any of the preceding embodiments, characterized in that the cover plate is secured to the housing by a metal clamp to form the sample chamber.

Embodiment 16

A sampler according to any of the preceding embodiments, characterized in that the first and second openings are the only openings formed in the sample cavity, an end of the

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inflow conduit being secured within the first opening and an end of the gas coupler being secured within the second opening.

Embodiment 17

A sampler according to any of the preceding embodiments, characterized in that a cross-sectional area of the inflow conduit is between 0.5 and 2 times of a cross-sectional area of the analysis zone.

Embodiment 18

A sampler according to any of the preceding embodiments, characterized in that the inflow conduit, the distribution zone, the analysis zone, the ventilation zone and the gas coupler are sequentially arranged in this order in the flow direction of the molten iron.

Embodiment 19

A sampler according to any of the preceding embodiments, in that the first face of the housing includes a ridge protruding therefrom and surrounding the ventilation zone, the analysis zone and the distribution zone.

Embodiment 20

A sampler according to any of the preceding embodiments, characterized in that when the cover plate and the housing are assembled together, the cover plate sits flush against the ridge of the housing along the first plane.

BRIEF DESCRIPTION OF DRAWINGS

The foregoing summary, as well as the following detailed description of preferred embodiments of the invention, will be better understood when read in conjunction with the appended drawings. For the purpose of illustration, there are shown in the drawings embodiments which are preferred. It should be understood, however, that the device and method are not limited to the precise arrangements and instrumentalities shown.

FIG. 1 is a side elevational view of an immersion sampling probe oriented in the immersion direction in accordance with one embodiment of the invention;

FIG. 2 is a top plan view of the immersion sampling probe of FIG. 1;

FIG. 3 is a side elevational view of the immersion sampling probe of FIG. 1 provided with a gas connector for connecting to a probe holder containing a pneumatic line;

FIG. 4 is front elevational view of the housing of a two-part sample chamber of the immersion sampling probe of FIG. 1;

FIG. 4A is a bottom plan view of the sample chamber housing shown in FIG. 4;

FIG. 5 is a front elevational view of the cover plate of the two-part sample chamber of the immersion sampling probe of FIG. 1;

FIG. 5A is a bottom plan view of the sample chamber cover plate shown in FIG. 5;

FIG. 6 is a cross-sectional side view of immersion sampling probe of FIG. 3 taken along a plane parallel to a longitudinal axis of the sample cavity;

FIG. 7 is a front view of the sample chamber housing containing a solidified hot metal sample therein and suitable for OES analysis without preparation;

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FIG. 7A is a side view of the sample chamber housing shown in FIG. 7;

FIG. 8 is front elevational view of the housing of a two-part sample chamber in accordance with another embodiment of the invention;

FIG. 8A is a bottom plan view of the sample chamber housing shown in FIG. 8;

FIG. 9 is a front elevational view of the cover plate configured to be assembled with the sample chamber housing of FIGS. 8-8A;

FIG. 9A is a bottom plan view of the sample chamber cover plate shown in FIG. 9;

FIG. 10 is a cross-sectional view of the sample cavity of the sample chamber housing of FIG. 4 taken along a plane perpendicular to a longitudinal axis of the sample cavity; and

FIG. 11 is cross-sectional view, not to scale, of the sample cavity of the sample chamber housing of FIG. 4 taken along a plane parallel to a longitudinal axis of the sample cavity.

DETAILED DESCRIPTION

The invention relates to an immersion sampling probe for accessing a sample of hot metal for direct analysis by OES.

Referring to FIG. 1, there is shown an immersion sampling probe 10, and more particularly a hot metal sampling probe 10. Most particularly, the probe 10 is suitable for immersion in and sampling of hot metal. The probe 10 comprises a measuring head 5. The measuring head 5 is preferably made of resin bonded silica sand. However, it will be understood by those skilled in the art that the measuring head 5 may be made of any material known to be suitable for forming a body to be immersed in hot metal.

The measuring head 5 is supported on a carrier tube 1. Preferably, the carrier tube 1 is a paper carrier tube. In use, a probe holder or lance (not shown) is preferably inserted into the interior volume of the carrier tube 1 to provide the mechanical action necessary to submerge the measuring head 5 below the surface of a bath of hot metal (not shown) in the immersion direction I.

The measuring head 5 comprises a sampling chamber 3 for collection and retrieval of a sample of hot metal. It will be understood by those skilled in the art that while the sample chamber 3 is described herein in terms of the immersion sampling probe 10, the sample chamber 3 may be utilized with any type of molten metal sampling device. Thus, the assembly and configuration of the sample chamber 3 described herein is applicable to any type of molten metal sampling device, not just the immersion sampling probe 10.

Preferably, the sample chamber 3 is a two-part sampling chamber. More particularly, referring to FIG. 2, the sample chamber 3 is composed of a housing 30 and cover plate 32. The housing 30 is preferably formed of one or more materials which are good thermal and electrical conductors, such as, but not limited to, aluminum, copper and other metals having similar thermal and electrical conductivity properties for being electrically coupled to the retrieved metal sample. Preferably, the housing 30 is made of aluminum. The mass of the closing plate 32 preferably accounts for 10 to 20% of the overall mass of the sample chamber 3. The housing 30 may be marked by an indestructible method with identification means.

The two parts 30, 32 of the sample chamber 3 are preferably held together by a clamp 4 (also referred to as a clip) with a compression force sufficient to resist a tendency of the two parts 30, 32 of the sampling chamber 3 to separate due to the force of hot metal flowing into and filling the

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sample chamber 3. The clamp 4 is preferably a metal clamp. However, it will be understood by those skilled in the art that the clamp 4 may be made of another suitable material which is capable of immersion in hot metal and provides the requisite compressive force.

Referring to FIG. 1, the measuring head 5 has a first end 12 and an opposing second end 14. The first end 12 of the measuring head 5 corresponds to an immersion end. The second end 14 of the measuring head 5 is configured to face the lance or probe holder. The sample chamber 3 has a first end 16 and an opposing second end 18. The first end 16 of the sample chamber 3 corresponds to an immersion end. It will be understood by those skilled in the art that the phrase “immersion end” means the end of the body which is first immersed into hot metal in the immersion direction I.

The sample chamber 3 includes a sample cavity configured to receive molten metal, as described in greater detail herein. The sample cavity extends from proximate the first end 16 toward the second end 18 of the sample chamber 3 along a longitudinal axis X (see FIG. 4).

The first end 16 of the sample chamber 3 is preferably attached to or otherwise provided with an inflow conduit 7. More particularly, the first end 16 of the sample housing 30 has a first opening 20 for receiving the inflow conduit 7 (see FIG. 4). The first opening 20 and thus the inflow conduit 7 are preferably aligned with the sample chamber 3, and more particularly the sample cavity. The inflow conduit 7 enables the flow of hot metal from the hot metal bath into the sample chamber 3. Thus, hot metal is introduced into the sample cavity of the sample chamber 3 in the immersion direction parallel to the longitudinal axis X of the sample cavity. The inflow conduit 7 is preferably made of a quartz material, more preferably a fused quartz material. However, it will be understood that the inflow conduit 7 may be made of any other suitable material, including, but not limited to, a ceramic material.

The inflow conduit 7 has a first end (not shown) and an opposing second end 22 (see FIGS. 4-4A). In at least one embodiment, the inflow conduit 7 is secured within the measuring head 5 by a bushing 6 (see FIG. 1). The bushing 6 is preferably made of a cement material. The second end 22 of the inflow conduit 7 is adhered or attached within the sample chamber 3 by an adhesive 27 in a substantially gas tight manner. More particularly, the second end 22 of the inflow conduit 7 is positioned entirely within the first opening 20 of the housing 30 of the sample chamber 3 and is adhered therein by the adhesive 27 to achieve a substantially gas tight joint. “Substantially gas tight” means that the seal or joint may be completely gas tight or gas tight to a large degree. In particular, regarding the joining of the inflow conduit 7 and the gas coupler 2 (described herein), the joints formed are preferably gas tight to the extent that the sample cavity is capable of being pressurized above the pressure level at the immersion depth.

Referring to FIGS. 1 and 3, the first end of the inflow conduit 7 corresponds to an immersion end. The first end is not visible on FIGS. 1 and 3, because it is covered by a first protection cap 8. More particularly, the first protection cap 8 is attached to the first end of the inflow conduit 7 in a substantially gas tight manner by adhesive 11. The first protection cap 8 is preferably made of metal, and more preferably steel. The first protection cap 8 may include an opening (not shown) (e.g., a 1 mm diameter hole) to ensure that the sample cavity can be sufficiently purged and that all entrapped air can be exhausted therefrom. A second protection cap 9, in turn, covers (and more specifically encompasses) the first protection cap 8. The second protection cap

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9 is attached to the first end 12 of the measuring head 5. Preferably, the second protection cap 9 is made of metal, and more preferably steel. In at least one embodiment, the second protection cap 9 is further protected by a covering of paper (not shown).

Referring to FIGS. 1-2 and 4, the second end 18 of the sample housing 30 includes a second opening 33 for receiving a coupler 2, and more particularly a gas coupler 2. The second opening 33 is thus a gas port which is preferably wholly contained within the housing 30. The coupler 2 is sealed to the housing 30 within the gas port 33 at the second end 18 of the sample chamber by an adhesive 26 to achieve a substantially gas tight joint. Thus, an end of the coupler 2 is positioned entirely within the body of the housing 30 of the sample chamber 3.

The coupler 2 is configured to mate with a conduit (not shown), and more particularly a gas conduit. More particularly, a first end of the gas conduit is attached to the coupler 2 and an opposing second end of the gas conduit is attached to a pneumatic system (not shown). The pneumatic system preferably supplies an inert gas to the sample chamber 3 via the gas conduit for purging and pressurizing the sample chamber 3. Examples of the inert gas which may be used to purge and pressurize the sample chamber 3 include, but are not limited to, nitrogen or argon. Preferably, the inert gas (e.g., nitrogen or argon) is at a pressure of 2 bar. The pneumatic system also facilitates the removal of exhaust gases from the sample chamber 3 via the gas conduit. When a pneumatic system is in communication with the sampling chamber 3 of the probe 10 via the coupler 2, there is a continuous gas path from the immersion end of the inflow conduit 7 to the sampling chamber 3 (i.e., along the longitudinal axis X) that is substantially leak-free, yet the sample chamber 3 is easily disassembled in order to access the sample.

Referring to FIG. 3, in one embodiment, the coupler 2 is provided with a gas connector 23 configured to mate with a corresponding receptacle on the probe holder. More particularly, the gas connector 23 is a push-on/pull-off type of connector assembly and includes an O-ring 24 for gas sealing to a mating surface on the probe holder.

In use, the measuring head 5 is immersed into a hot metal bath and the sample chamber 3 is purged and pressurized by the inert gas which is supplied by the pneumatic system and which travels from the coupler 2 toward the inflow conduit 7 along the longitudinal axis X. After the measuring head 5 is immersed below the surface of the hot metal bath, the second protection cap 9 and the covering of paper (if present) melt due to the heat of the hot metal, thereby exposing the first protection cap 8 to the hot metal. Subsequently, the first protection cap 8 also melts, thereby placing the sample chamber 3 in fluid communication with the hot metal bath via the inflow conduit 7. More particularly, once the second protection cap 8 melts, the pressure of the inert gas exits from the sample chamber 3 via the open inflow conduit 7 (i.e., via the first end of the inflow conduit 7) until the pneumatic system reverses from a purge mode to an exhaust or vacuum mode. Hot metal then enters the sample chamber 3 through the inflow conduit 7, particularly from the first end to the second end 22 and subsequently into the sample cavity of the sample chamber 3, while gas is exhausted out of the sample chamber 3 through the coupler 2. The gas is preferably exhausted by the natural ferro-static pressure of the filling molten metal but may also be exhausted by a slight vacuum applied to the gas conduit by remote equipment.

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FIGS. 4-6 show the two-part sample chamber 3 of probe 10 in greater detail. The housing 30 of the sample chamber 3 has a first side or face 40 and an opposing second side or face 42 (see FIGS. 4A and 6). The first face 40 is an analysis face, meaning it is the geometric side of the housing 30 in which the sample is collected and which is thus configured to be positioned face down upon the stage of optical emission spectrograph during analysis. The down direction, in this case, is a direction toward the spark source of an OES system. The first face 40 extends between the immersion end and the opposing end of the housing 30. More particularly, the first face 40 extends in a first plane AF from the first end 16 toward the second end 18 of the sample chamber 3. At the second end 18 of the sample chamber 3, there is provided a gas port 33 which is preferably wholly contained within the housing 30. The gas port 33 receives the coupler 2 (as shown in FIG. 1 or 3) which, as described herein, is sealed to the housing 30 in a substantially gas tight manner by the adhesive 26 (see FIG. 3).

Referring to FIGS. 4 and 6, portions of the first face 40 are hollowed out to form different regions or zones of the sample chamber 3 for ventilation and the collection of hot metal. More particularly, the first face 40 of the housing 30 includes various depressions which collectively form the sample cavity of the sample chamber 3, as follows: a first region 34 proximate the first end 16 of the sample chamber 3 and in direct communication with the inflow conduit 7, a second region 35 overlying the first region 34, a third region 36 adjacent to the second region 35. The first face 40 also includes an additional depression in the form of a fourth region 38 proximate the second end 18 of the sample chamber 3 and in direct communication with the gas port 33. The gas port 33 (and thus the coupler 2) and the inflow conduit 7 are located in the housing 30, such that they are in direct communication and aligned with the sample cavity of the sample chamber 3. More particularly, the gas port 33 and the inflow conduit 7 preferably extend parallel to the sample cavity of the sample chamber 3, and more preferably the gas port 33 and the inflow conduit 7 extend along a common longitudinal axis X of the sample cavity of the sample chamber 3.

Referring to FIG. 6, the fourth region 38 is a connecting volume defined by an indentation or depression formed in the first face 40 of the housing 30 of the sample chamber 3. The connecting volume 38 thus has an open end 38a at the first face 40. The connecting volume 38 is in gas communication with the gas port 33. As the hot metal generally solidifies in the third region 36, as described herein, the connecting volume 38 is generally not considered to be part of the sample housing cavity for receiving the hot metal does.

The third region 36 is a ventilation zone which is in gas communication with the connecting volume 38. The ventilation zone 36 is defined by an indentation or depression formed in the first face 40 of the housing 30. The ventilation zone 36 thus has an open end 36a at the first face 40 and an opposing closed bottom end 36b. A centerline of the ventilation zone 36 preferably aligns with the second region 35 and the gas coupler 2.

The second region 35 is an analysis zone. The analysis zone 35 is defined by an elongated indentation or depression formed in the first face 40 of the housing 30. The analysis zone 35 thus has an open end 35a at the first face 40 and an opposing partially closed bottom end 35b. More particularly, the physical boundary of the closed bottom end 35b only extends across a portion of the length of the analysis zone 35.

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In at least one embodiment, the opposing ends (i.e., the leading end and the trailing end in terms of the immersion direction I) of the analysis zone 35 are rounded for ease of machining. However, it will be understood by those skilled in the art that the ends may be any shape.

A portion of the analysis zone 35 overlays the first region 34 of the sample chamber 3. More particularly, the leading end of the analysis zone 35 (i.e., the leading end of the analysis zone 35 proximate the immersion end 16 of the sample chamber 3) overlays and is in direct communication with the first region 34 (see FIG. 6). Thus, the portion of the analysis zone 35 which overlays the first region 34 is not physically bounded by the closed bottom end 35b. The first region 34 is a distribution zone which is in direct communication with the inflow conduit 7. More particularly, hot metal is introduced directly into the distribution zone 34 from the second end 22 of the inflow conduit 7. As such, the inlet conduit 7 is located so as to be in direct flow communication with the distribution zone 34 in a direction parallel to the longitudinal axis X.

Again, there is no physical delineation between the analysis zone 35 and the distribution zone 34. However, these are considered separate zones in terms of the prescribed dimensions for the practice of the invention. In particular, the imaginary boundary between the analysis zone 35 and the distribution zone 34, as indicated by a dashed line 35c on FIG. 6, is essentially an extension of the closed bottom end 35b, meaning the boundary 35c between the analysis zone 35 and the distribution zone 34 lies in the same as the closed bottom end 35b. The analysis zone 35 is preferred to be of a uniform depth overlying the distribution zone 34, as discussed in greater detail herein.

Collectively, the connecting volume 38, the ventilation zone 36, the analysis zone 35 and the distribution zone 34 form the hollow volume of the sample chamber 3. The ventilation zone 36, the analysis zone 35 and the distribution zone 34 collectively comprise the cavity receiving the hot metal, meaning the sample cavity in which the hot metal is introduced along the longitudinal axis X, collected, subsequently solidified to form a solidified metal sample S, and ultimately directly analyzed. The ventilation zone 36, the analysis zone 35 and the distribution zone 34 are contiguous regions.

Referring to FIGS. 4 and 6, the first face 40 of the housing 30 includes a raised portion 39 that encompasses the depressions of the connecting volume 38, the ventilation zone 36, the analysis zone 35 and the distribution zone 34. More particularly, the raised portion, herein referred to as the ridge 39, peripherally surrounds the collective volume of the connecting volume 38, the ventilation zone 36, the analysis zone 35 and the distribution zone 34. The upper or distal rim 39a of the ridge 39 is preferably at a height of 0.2 mm to 0.5 mm, and more preferably 0.3 mm, relative to the remainder of the first face 40 (i.e., relative to the first plane AF). Thus, the distal rim 39a of the peripheral ridge 39 lies in a second plane AP which is spaced apart from the first plane AF of the first face 40. The second plane AP is referred herein as the analysis plane. When the sample chamber 3 is filled with metal, the analyzable surface AS of the solidified metal sample AS lies in the analysis plane AP, as described herein in greater detail.

Referring to FIGS. 5-5A, the cover plate 32 need not be formed of the same material as the housing 30. Unlike the housing 30, the cover plate 32 does not have to be formed of a material which is a good electrical conductor. For example, the cover plate 32 may be formed of fused silica

or a refractory ceramic material. Preferably, however, the cover plate 32 is formed of the same material as the housing 30.

Preferably, for practical purposes of assembly, the cover plate 32 is approximately the same width and length as the housing 30. However, it will be understood that the cover plate 32 is not limited to such dimensions, and may have a width and length greater or less than that of the housing 30.

The cover plate 32 has a first side or face 44 and an opposing second side or face 46. The cover plate 32 preferably has a thickness between 1 mm and 5 mm extending from the first face 44 to the second face 46. The first face 44 of the cover plate 32 is configured to face the housing 30, and more particularly the first face 40 of the housing 30, in the assembled configuration of the sample chamber 3. A sealing member 31 is provided on the first face 44 of the cover plate 32 so as to be positioned between the housing 30 and cover plate 32 in the assembled configuration of the sample chamber 3. The sealing member 31 is preferably a gas sealing member. More particularly, the sealing member 31 is a gasket. The gasket 31 is preferably dimensioned so as to encompass or surround the ridge 39 in the assembled configuration of the sample chamber 3. The gasket 31 may be of any shape. Preferably, however, the gasket 31 is formed in the same shape as that of the ridge 39 of the first face 40 of the housing 30.

In at least one embodiment, the gasket 31 is preferably formed of silicone or any similar polymer. It will be understood by those skilled in the art that the gasket 31 may be formed of any material which would provide a gas tight seal between the cover plate 32 and the housing 30. After the material of the gasket 31 is applied to the first face 44 of the cover plate 32, the gasket 31 is allowed to dry before the cover plate 32 is assembled with the housing 30 and secured together by the clamp 4, thus ensuring that the gasket 31 does not adhere to the housing 30.

It will be understood by those skilled in the art that the gasket 31 may alternatively be formed as an O-ring or of a flat gasket material without departing from the scope of the invention. For example, in another embodiment, the gasket 31 is a plastic foil applied as a flat gasket preferably having a thickness of 0.04 to 0.1 mm. For example, the flat gasket may be formed of the surface protection tape, Product No. 4011a, manufactured by 3M™.

In the assembled configuration of the sample chamber 3, as shown in FIG. 6, the cover plate 32 and the housing 30 are assembled together to form the sample cavity including the distribution zone 34, the analysis zone 35 and the ventilation zone 36. Preferably, the cover plate 32 rests on the ridge 39 of the housing 30 (i.e., in the analysis plane AP) and the gasket 31 contacts the first face 40 of the housing 30 such that the gasket 31 surrounds or encompasses the ridge 39. More particularly, in the assembled configuration of the sample chamber 3, the cover plate 32 preferably sits flush against the ridge 39 in the analysis plane AP and is sealed to the first surface 40 of the housing 30 in a gasket-type fit due to the seal of the gasket 31 against the first surface 40. However, it will be understood that the cover plate 32 and the housing 30 may be assembled together along a plane that extends above the ridge 39 and the analysis plane AP.

Thus, the cover plate 32 closes the sample cavity of the sample chamber 3. Again, the sample cavity of the sample chamber 3 is the volume in which hot metal is introduced along the longitudinal axis X from the inflow conduit 7, collected and subsequently rapidly cooled to form the solidified metal sample S. As such, there are only two openings formed in the assembled sample chamber 3, namely the first

opening 20 in communication with the inflow conduit 7 and the opening of the gas port 33 in communication with the coupler 2.

The analysis surface of the solidified metal sample S housed with the sample cavity lies in the analysis plane AP. Further, the first opening 20 and the associated inflow conduit 7 and the gas port 33 and the associated coupler 2 are spaced apart from and do not intersect the analysis plane AP.

Hereinafter, a length L of each zone 34, 35, 36 is described in terms of a dimension parallel to and aligned with the longitudinal axis X of the sample cavity, a width W of each region 34, 35, 36 is described in terms of a dimension perpendicular to the longitudinal axis X; and a depth D of each zone 34, 35, 36 is described in terms of a dimension perpendicular to the longitudinal axis X and perpendicular to the width dimension. More particularly, a depth of each zone 34, 35, 36 is measured from a point along the analysis plane AP to the bottom end or boundary of each zone 34, 35, 36, because the sample cavity of the sample chamber 3 is bounded on one end by the zones 34, 35, 36 and on the other end by the cover plate 32 lying in the analysis plane.

The length L, width W and depth D dimensions are most clearly shown in FIG. 4, FIG. 6 and FIG. 11. The cross-sectional area dimension, discussed herein, is equivalent to a width W dimension multiplied by a depth D dimension (see FIG. 10).

The analysis zone 35 has a width W_A of between 8 and 12 mm, preferably 10 mm. The length L_A of the analysis zone 35, extending from the leading end to the trailing end (the trailing end of the analysis zone corresponding to the leading end of the ventilation zone 36) is 25 to 35 mm, preferably 30 mm. The depth D_A of the analysis zone 35 extends from a point along the analysis plane AP to the closed bottom end 35b and boundary 35c (i.e., the base of the depression). The depth D_A of the analysis zone 35 is 0.5 to 1.5 mm, preferably 1 mm. If the depth D_A of the analysis zone 35 is greater than 1.5 mm, then the solidified white structure of the iron sample S could not be prevented from cracking. That is, the 0.5 mm to 1.5 mm depth D_A of the analysis zone 35 is a critical aspect of the invention.

In at least one embodiment, the width W_A of the analysis zone 35 gradually increases from proximate the immersion end 16 toward the opposing end 18 for a distance corresponding to the portion overlying the distribution zone 34. The, upon reach a maximum width W_A , the width W_A of the analysis zone 35 tapers slightly along the longitudinal axis X, such that the cross-sectional area of the analysis zone 35 (i.e., the cross-sectional area of the analysis zone 35 taken along the plane perpendicular to the longitudinal axis X as shown in FIG. 10) is at a maximum where the distribution zone 34 ends and tapers slightly toward the ventilation zone 36. More particularly, the walls defining the width of the analysis zone 35 (i.e., the walls extending perpendicular to the first face 40) are slightly tapered in the direction of the longitudinal axis X, such that the width of the analysis zone 35 is greater at the end of the distribution zone 34 and decreases in the direction of the longitudinal axis X toward the ventilation zone 36. As such, the analysis zone 35 can accommodate shrinkage of the solidifying hot metal without undue stress on the thin cross section of the solidified metal sample S.

The cross-sectional area of the inflow conduit 7, that is the cross-section of the inflow conduit 7 taken along the plane perpendicular to the longitudinal axis X as shown in FIG. 10, is dependent upon the cross-sectional area of the analysis

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zone 35 and the distribution zone 34. Preferably, the cross-sectional area of the inflow conduit 7 is between 0.5 and 2 times the cross-sectional area of the analysis zone 35. Preferably, the cross-sectional area of the inflow conduit 7 is between 0.20 and 0.70 times the largest cross-sectional area of the distribution zone 34 and thus lowers the inlet velocity required for metal mixing. More preferably, the cross-sectional area of the inflow conduit 7 is 0.55 times the largest cross-sectional area of the distribution zone 34. If the cross-sectional area of the inflow conduit 7 is too small (i.e., less than 0.5 times the cross-sectional area of the analysis zone 35 and/or less than 0.20 times the largest cross-sectional area of the distribution zone 34), then there is not enough deceleration of the inflowing hot metal to accomplish optimum mixing and reduce turbulent flow, and there is poor filling. If the cross-sectional area of the inflow conduit 7 is too large (i.e., greater than 2 times the cross-sectional area of the analysis zone 35 and/or greater than 0.70 times the largest cross-sectional area of the distribution zone 34), then the distribution zone 34, when filled, adds sensible heat to the hot metal sample that must be removed by more housing 30 mass, thus moving further from an economic solution.

The distribution zone 34, as described earlier, lies under the analysis zone 35 and therefore does not influence the overall length L_A of the analysis zone 35. The volume of the distribution zone 34 is bounded by the analysis zone 35, and more particularly by the boundary 35c, on its upper end, as well as by its opposing side walls 34a, 34b and its bottom surface 34c (see FIG. 10). The side walls 34a, 34b are substantially perpendicular to the analysis plane AP. The width W_D of the distribution zone 34 (i.e., the distance spanning the side walls 34a, 34b) also preferably does not exceed the width W_A of the analysis zone 35 and is preferably not less than the inner diameter of the inflow conduit 7. Preferably, the width W_D of the distribution zone 34 is equal to the inner diameter of the inflow conduit 7. A first portion of the bottom surface 34c (i.e., the surface opposite to the analysis zone 35) of the distribution zone 34 extends in a horizontal plane parallel to the longitudinal axis X. A second portion of the bottom surface 34c is angled, and more particularly extends upwardly at an angle α , and intersects with the closed bottom end 35b of the analysis zone 35 at an angle α between 40° and 90°, preferably 60°. The distribution zone 35 ends at this intersection. As such, the depth of the distribution zone 34 decreases in the flow direction of the hot metal from the inflow conduit 7 toward the gas coupler 2.

The depth D_V of the ventilation zone 36 ranges between approximately 0.1 and 1 mm, the length L_V of the ventilation zone 36 is approximately 5 mm, and the width W_V of the ventilation zone 36 is preferably equal to or less than the width W_A of analysis zone 35. The depth D_V of the ventilation zone 36 is at its maximum at the end closer to the immersion end 16 of the sample chamber 3. That is, the depth D_V of the ventilation zone 36 decreases slightly from the immersion direction I toward the connecting volume 38. More particularly, a gradual reduction in the depth D_V of the ventilation zone 36 from the trailing end of the analysis zone 35 to the end of the ventilation zone 36 from 1 mm to 0.2 mm is preferred.

There are no increases in the width of the sample cavity from the end of the distribution zone to the gas coupler 2, or increases in the depth dimensions of the sample cavity in the flow direction of the molten steel from the inflow conduit 7 toward the gas coupler 2, such that metal shrinking during solidification can freely move towards the inflow conduit 7.

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The cross-sectional area of the analysis zone 35 (i.e., the width W_A of the analysis zone 35 multiplied by the depth D_A of the analysis zone 35) is between 2.5 and 10 times the cross-sectional area of the ventilation zone 36 (i.e., the width W_V of the ventilation zone 36 multiplied by the depth D_V of the ventilation zone 36). Therefore, the maximum cross-sectional area of the ventilation zone 36 is between 2 and 8 mm².

FIGS. 8-9A show an alternative sample chamber which is essentially the same as the sample chamber 3, except for certain differences in the configurations of the housing 60 and cover plate 62, as discussed hereinafter. The housing 60 includes an connecting volume 68, a ventilation zone 66, an analysis zone 65 and a distribution zone 64 which are the same as the connecting volume 38, a ventilation zone 36, an analysis zone 35 and a distribution zone 34, respectively, of the housing 30. The housing 60 is also provided with a gas port 63 at one end, similar to the gas port 33 of the sample chamber 3, and an inflow conduit 67, similar to the inflow conduit 7 of the sample chamber 3. The housing 60 also has a first side or face 70 which is an analysis face and which extends in a first plane AF, and an opposing second face 72. Unlike the housing 30, the housing 60 does not include a raised ridge (i.e., the raised ridge 39 of the housing 30). Referring to FIGS. 9-9A, the cover plate 62 has a first face 74 configured to face the housing 60 in the assembled configuration of the sample chamber. A gasket 61 is provided on the first face 74 of the cover plate 62 so as to be positioned between the housing 60 and cover plate 62 in the assembled configuration of the sample chamber. Unlike the cover plate 32 of the sample chamber 3, the cover plate 62 further includes a raised central portion 69 extending from its first face 74. The raised central portion 69 has a height between 0.2 mm and 0.5 mm, preferably 0.3 mm. The gasket 61 surrounds or encompasses the raised central portion 69.

In the assembled configuration of the sample chamber, the raised central portion 69 of the cover plate 62 sits flush against the housing 60, with gasket 61 to sealing to the first face 70 of the housing 60. Thus, the cover plate 62 closes the open volume of the sampling chamber hollowed out from the material of the housing 60 to form the connecting volume 68, a ventilation zone 66, an analysis zone 65 and a distribution zone 64. In this embodiment, analysis plane is equal to the plane AF of the analysis face.

Retrieving a white structure hot metal sample of the invention suitable for analysis on an OES from a hot metal bath is accomplished by the following procedure. The probe 10 is pneumatically coupled to the probe holder with the simple push-on, pull off connector 23. The connector 23 is either directly attached to the sampling chamber 3 by the coupler 2 or at a distance joined by a pneumatic line. Closing of the gas circuit provides for a slight overpressure of inert purge gas. Using the probe holder for mechanical advantage, the probe 10 is immersed in a hot metal bath and remains at a predetermined distance beneath the metal surface for a specified duration. During this immersion, the protective cap 9 of the measuring head 5 which is designed to withstand destruction while passing through the slag floating upon the metal surface, melts away, thus exposing the smaller protective cap 8 of the inflow conduit 7. As the first protection cap 4 also subsequently melts, the overpressure of inert gas is released and the inert purge gas flows from the probe holder through the gas connector 23 (if present) and the coupler 2 into the connecting volume 38, the ventilation zone 36, the analysis zone 35, the distribution zone 34 which underlies the analysis zone 35, and the internal volume 7a of the inflow conduit. The gas connector 23 (if present) and the

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coupler 2 are adhered to the housing 30 in a substantially gas tight manner by adhesive 26 and the inflow conduit 7 is adhered to the housing 30 in a substantially gas tight manner by adhesive 27. More particularly, the second end 22 of the inflow conduit 7 is wholly contained within the housing 30 and adhered therein in a substantially gas tight manner by adhesive 27.

This purge gas removes the potentially oxidizing ambient atmosphere initially within the sampling chamber 3 and continues to flow for a few more seconds which allows for remnants of the second protective cap 9 and any slag that had been dragged down attached to the measuring head 5 to be flushed away. The pneumatic valves are then switched momentarily from purge to exhaust or vacuum, such that the direction of the purge gas is reversed to remove the over-pressure, particularly by allowing the excess pressure within the sample chamber 3 to exhaust by the reverse route as mentioned above and exit the sample chamber 3. With this, hot metal from the hot metal bath (not shown) enters into and fills the inflow conduit 7 and debouches from the volume 7a of the inflow conduit 7 into the distribution zone 34 of the sample chamber 3. The hot metal is then fed to the analysis zone 35 which overlies the distribution zone 34 and fills the analysis zone 35. A portion of the hot metal will continue to flow towards the coupler 2 at the second end of the sample chamber 3, thereby at least partially or even completely filling the narrow ventilation zone 36. The probe holder now moves in the opposite direction removing the filled sample chamber from the molten bath. One skilled in the art will recognize that the basic description of the probe holder and the pneumatic valves and switches necessary to carry out pneumatically assisted sampling are known in the art and not part of the present invention.

The small size of the retrieved liquid hot metal is chilled to a white solidification structure by the housing 30 and cover plate 32, as the measuring probe is removed from the processing vessel. The rate of heat extraction from the molten sample cools the hot metal to room temperature within one minute, which essentially eliminates all external cooling required in conventional sampling and allows immediate de-molding without the potential of surface oxidation that would normally occur when exposing a hot metallic surface to an oxygen containing atmosphere. Also, the sample chamber 3 is of a mass ratio (i.e., 9 to 12) suitable to chill the hot metal from temperatures as high as 1500° C. to 100° C. promoting a pure white solidification structure within one minute.

The slight taper in the ventilation zone 36 promotes chilling of the hot metal before it reaches the gas coupler 2 and ensures that the solidified metal sample can shrink towards the analysis zone 35. More particularly, the hot metal which fills the ventilation zone 36 freezes in the ventilation zone 36. This is because the sample S may crack if hot metal enters the connecting volume 38.

Rapid chill of the hot metal collected in the sample chamber 3 is achieved largely due to the relationship between the mass of the sample chamber 3 (i.e., the mass of the cover plate 32 plus the mass of the housing 30) and the volume of the collected hot metal which is converted to a mass. In the case of hot metal, which has an approximate molten density of 6.8 g/cm³, the ratio of the mass of the sample chamber 3 to the mass of the hot metal collected within the sample chamber 3 (calculated based on the volume collected therein) is preferably in the range of 9 to 12, preferably 10, in order to ensure an oxide free analysis surface AS.

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Thus, while the internal voids of the analysis zone 35, ventilation zone 36 and distribution zone 34 must satisfy specific dimensional criteria, the overall dimensions of the sample chamber 3 (composed of the cover plate 2 and the housing 30) must also satisfy certain criteria to achieve the desired mass ratio of the mass of the sample chamber 3 to the mass of the hot metal collected within the sample chamber 3. One skilled in the art would understand that the overall width, depth and/or length of the housing 30 or cover plate 32 may be adjusted as necessary to increase or decrease the mass of the housing 30, without changing the internal voids necessary to create the sample cavity.

In particular, once allowances are made for the outer diameters of both the second end 22 of the inflow conduit 7 and the gas coupler 2, such that both are wholly contained within the sample housing, one or more dimensions of the housing 30 can be easily adjusted to meet the mass ratio requirement in order for the mass of the sample chamber 3 (where the cover plate 32 accounts for 10 to 20% of the mass of the sample chamber 3) to be between 9 to 12 times the mass of the metal sample S.

Preferably, the hot metal freezes in the analysis zone 35 against the cover plate 32, and more particularly against the first surface 44 of the cover plate 32, thereby forming the analysis surface AS of the sample S which is the surface configured to be positioned face down upon the stage of optical emission spectrograph during analysis of the sample S. The analysis surface AS extends in the plane where the first face 44 of the cover plate 32 directly contacts surface formed by the ridge 39 (i.e., the analysis plane AP). For example, in the embodiment of FIGS. 1-7A, the analysis surface AS extends in the same plane as the ridge 39 of the housing 30, namely the analysis plane AP. More particularly, both the analysis surface AS of the solidified metal sample S and the surrounding metal ridge 39 extend the analysis plane AP to help close the opening of the OES. In the embodiment of FIGS. 8-8A, discussed in greater detail herein, the analysis surface AS would extend in the plane where the raised central portion 69 of the cover plate 62 sits flush against the first face 70 of the housing 60.

When the hot metal freezes in the sample chamber 3 as such, the solidified metal sample S is formed inseparably from the housing 30. The measuring head 5 is easily fractured allowing removal of the sampling chamber 3 from the carrier tube 1 in the forward, immersion direction I. The clip 4 holding the two part sample chamber 3 is removed. Unlike conventional sampling devices, the sample S remains attached to the sample housing 30. Therefore, the term "sample", when referring herein to the metal coupon delivered to the OES, refers to the inseparable combination of the retrieved solidified sample and the sample housing 30.

The sample S is then delivered to the OES by conventional means and directly analyzed by the OES without surface preparation. The rapid chill of the sample S avoids the surface oxidation normally encountered during the de-molding step. This eliminates the need for mechanical grinding and facilitates rapid analysis of the sample S and reporting the chemistry to the metal process awaiting these results. Because the inflow conduit 7 and the gas port 33 (as well as the gas coupler 2) are situated within the housing 30 spaced apart from, and more particularly below, the analysis plane (as well as below the analysis face 40), rather than straddling both sides as is normally encountered in prior art clamshell molds, it is not necessary to remove the inflow conduit 7 and the gas coupler 2 from the housing 30, in order to obtain an oxide free surface, thus allowing for the creation of a white iron solidified sample that can be directly placed

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on an OES without preparation. That is, no part of the inflow conduit 7 and gas port 33/gas coupler 2 intersects with the analysis plane AP, such that the inflow conduit 7 and the gas port 33/gas coupler 2 do not interfere with the analysis plane AP.

The inseparability of the sample S and the housing 30 results in an extension of the housing 30 on either side of the solidified metal (i.e., by the ridge 39) along the analysis plane provides multiple improvements over the prior art. Conventional prior art samples completely cover the analysis opening of the OES, and thus have a sample size that has more material than is needed for an acceptable metal sample. During OES, the spark should not jump to the edge material of the OES sample stage, so this opening is purposefully rather large as previously described. Inert gas is purged into the spark chamber during analysis so that leaks between the sample S to be analyzed and the spectrometer stage cannot be tolerated.

The invention utilizes the inseparability of the sample S and the housing 30 to also provide a portion of the housing 30 surface for covering the analysis opening. The sampler housing 30 extending perpendicular to the elongation axis allows for an analysis zone to be just slightly larger than the burn area of the OES spark. Because of this extension of the analysis plane AP by the sampler housing 30, the volume of the hot metal filling the analysis zone 35 of the sampler housing 30 can be much smaller. This reduced volume translates to reduced heat input so that together the heat of the hot metal filling the distribution zone 34, analysis zone 35 and ventilation zone 36 is substantially less than prior art devices, and therefore can be rapidly chilled to achieve a desired white iron structure.

Referring to FIGS. 7-7A, there is shown a disassembled sample chamber 3. More particularly, FIGS. 7-7A show the housing 30 containing a solidified metal sample S inseparably contained therein with the cover plate 32 not shown as it has been disassembled from the housing 30. The housing 30 containing the solidified metal sample S, in the form shown in FIGS. 7-7A, may be used for direct analysis by OES. The analysis surface AS comprises the surface of the portion 55 of the sample S formed in the analysis zone 35 which sits above the metal filling distribution zone 34. The remaining portion 56 of the sample S extending from and contiguous with the analysis zone portion 55 is made up of metal which has flowed into and solidified within the ventilation zone 36 and, as a last resort, possibly the connecting volume 38. The remaining portion 56 of the sample S may thus include irregularities, such as the irregular structure 58, which do not influence the subsequent OES analysis. The analysis surface AS lies in the analysis plane AP and there are no parts or extraneous adhering materials which may break the analysis plane AP.

The various zones 34, 35, 36 of the sample chamber 3, as discussed above, correspond to different portions of the solidified metal sample S formed in the sample chamber 3. As such, the dimensions of the ventilation zone 36, analysis zone 35 and distribution zone 34 correspond to the dimensions of various portions of the solidified metal sample S formed therein. For example, a depth of each of the zones 36, 35, 34 corresponds a thickness of a corresponding portion of the solidified metal sample S. In particular, the ratio of the length L to the depth D (L/D) of each zone 34, 35, 36 (and thus the corresponding ratio of the various segments of the sample S) is a critical parameter of the invention. In particular, the distribution zone 34, analysis zone 35 and ventilation zone 36 are preferably structured as a plurality of contiguous segments extending from proximate

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the immersion end 16 to proximate the opposing end 18. Each segment has a length to depth (L/D) ratio. The L/D ratios of the segments successively increase as the distance from the first opening 20 increases. That is, the L/D ratio of one segment is greater than the L/D ratio of an adjacent preceding segment of equal length in a direction from the immersion end 16 toward the opposing end 18. This means that the thickness of the resulting sample S decreases in this same direction from one segment to the next (i.e., in the flow direction).

With all the basic geometries of the various zones 34, 35, 36 of the sample chamber 3 being calculated as discussed above, and using economical selection of the design parameters, the critical parameter of the L/D ratio can be satisfied, knowing that at each cross section of any of the aforementioned zones or segments, the sample chamber housing 30 facilitates solidification of the metal sample S without variations (particularly increases) in the depth D dimension of the sample cavity in the direction along the longitudinal axis X beginning from the inflow conduit 7 and extending to the gas coupler 2, as well as in the thickness dimension of the sample S in the same direction.

In order to avoid crack formation in the sample S during solidification and cooling to room temperature, a summation of the L/D ratio of all segments of the sample cavity, as discussed in greater detail herein, along the total length of the sample cavity (i.e., the length L_A of the analysis zone 35 plus the length L_V of the ventilation zone 36), divided by the depth D of the corresponding segments (i.e., the ratio L/D) must be greater than 25. That is, the sum of the L/D ratio of each of the individual segments of the sample cavity must be greater than 25. The L/D ratio of individual segments can be selected as equally spaced segments or convened groupings as long as the total length L of the sample cavity is considered. For segment 34, it is easier to calculate this as two sections as demonstrated later where in the section that the thickness of the sample changes, i.e., the depth of the cavity changes within the segment, D is taken as the sum of the largest depth in a direction from the immersion end of the segment plus the largest depth at the end opposing the immersion end of the segment both divided by 2. This calculation can be used for all segments that show depth variation over the length. Preferably, the L/D ratio of each individual segment increases in a direction from the immersion end and the inflow conduit 7 toward the gas coupler 2 (i.e., the depth of the sample cavity and correspondingly the thickness of the sample S decreases).

To better explain the L/D ratio, FIG. 11 shows the plurality of segments or sections of the sample cavity including the distribution zone 34, the analysis zone 35 and the ventilation zone 36. For purposes of calculating a total L/D ratio, the sample cavity (and thus also the sample S) may be segmented as follows, but may be segmented in another manner.

A first segment S1 of the sample cavity comprises a first portion of the analysis zone 35 and a first portion of the underlying distribution zone 34. The first segment S1 has a length L_{S1} extending from the first end 80 of the analysis zone 35 and distribution zone 34 proximate the inflow conduit 7 to a first intermediate point 84. The first intermediate point 84 corresponds to a point in the housing 30 just before the bottom surface 34c of the distribution zone 34 begins to angle upwardly toward the ventilation zone 36. Generally, the length L_{S1} of the first segment S1 is equal to or less than the diameter, and more particularly the inner diameter, of the inflow conduit 7. Other distances are possible however more preferably, the length L_{S1} of the first

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segment S1 is equal to the radius of the inflow conduit 7. The depth of the first segment S1 is the sum of the depths of the corresponding portions of the analysis zone 35 and distribution zone 34 in which the first segment S1 was formed. The depth of the distribution zone 34 corresponding to the first segment S1 is measured from the boundary 35c to the horizontally-oriented bottom surface 34c, and is equal to the calculated diameter of the inflow conduit 7 plus 1 mm.

The second segment S2 of the sample cavity comprises a second portion of the analysis zone 35 and a second portion of the underlying distribution zone 34. The second segment S2 has a length L_{S2} extending from the first segment S1, and more particularly the first intermediate point 84, to a second intermediate point 86 which corresponds to a point in the housing 30 at which the bottom surface 34c intersects with the bottom end 35b of the analysis zone 35. Because the intersection angle is generally known (e.g., the angle is preferably 60°), the length L_{S2} of the second segment S2 can be calculated. The depth of the second segment S2 is defined, as above, by the largest depth along 84 and largest depth along 86 of the corresponding portions of the analysis zone 35 and distribution zone 34, both divided by 2.

The third segment S3 of the sample cavity comprises the remaining portion of the analysis zone 35, and has a length L_{S3} extending from the second intermediate point 86 to a third intermediate point 88 which corresponds to the end of the analysis zone 35 and the beginning of the ventilation zone 36 of the housing 30. The length L_{S3} of the third segment S3 can generally be easily calculated since the overall length of the analysis zone 35 is known. The third segment S3 has a depth equal to the depth of the corresponding portion of the analysis zone 35.

The fourth segment S4 of the sample cavity comprises the ventilation zone 36. The ventilation zone 36 depth has been chosen for ease of machining, although an equally valid other depth within the range of this parameter can be chosen.

In order to create a sample housing 30 which will solidify hot metal to a white carbide structure, crack free sample of high homogeneity according to the invention, the following examples provide exemplary configurations according to the invention, but it will be understood that many other configurations are possible within the scope of the invention.

Example 1

A sample housing 30 of aluminum is machined according to FIGS. 1-6. The analysis zone 35 has a uniform depth D_A of 1 mm above the distribution zone 34. The surface area of the analysis zone 35, for Example 1, is determined from the number of analysis spots desired for OES analysis. More surface area can be provided for, however, 2-4 analysis spots are common, with 4 analysis spots being preferred. Since the typical OES analysis spot can be between 6-8 mm and it is desirable not to overlap spots, the length L_A of the analysis zone 35 is chosen to be 25 mm to accommodate 3 analysis spots. It will be understood that the number of spots selected does not change the invention, as one skilled in the art can select more spots, while understanding that increasing the length of the sample S and therefore all components of the sample chamber 3 is limited only by practical consideration for the size of the spectrograph. Also, as the sample chamber 3 size increases, material costs increase, thereby leading away from providing an economic solution. Less analysis spots may also be selected, but normally 2 spots are the minimum.

The width W_A of the analysis zone 35 is similarly selected to be 10 mm with a slight taper in cross section, such that the

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maximum cross-sectional area (i.e., depth times width) is toward the immersion direction I. Thus, the largest cross-sectional area of the analysis zone 35, which is located in the immersion direction I and more particularly proximate the inlet conduit 7, is 10 mm² (i.e., depth of 1 mm multiplied by width of 10 mm). Because the cross-sectional area of the inflow conduit 7 is between 0.5 and 2 times the cross-sectional area of the analysis zone 35, the cross-sectional area of the inflow conduit 7 of this Example can be between 5 and 20 mm². The inflow conduit 7 is a quartz tube. Therefore, the inner diameter of the inflow conduit 7 is between 2.5 and 5.1 mm. For this example, the inflow conduit 7 has an inner diameter of 5 mm (i.e., cross-sectional area of 19.6 mm²). Because the cross-sectional area of the inflow conduit 7 is between 0.20 and 0.70 times the largest cross-sectional area of the distribution zone 34, the cross-sectional area of the distribution zone 34, with rounding, can be between approximately 28 and 98 mm². The second portion of the bottom surface 34c of the distribution zone 34 intersects the bottom end 35b of the analysis zone 35 at an angle of 60°.

The cross-sectional area of the ventilation zone 36, at the largest area, is 1 mm². Since the width of the analysis zone 35 is 10 mm, the average depth D_V of the ventilation zone 36 is 0.2 mm.

The analysis portion of a sample S created using the housing 30 of Example 1 thus has a length of 25 mm and a thickness of 1 mm (i.e., corresponding to the analysis zone 35 dimensions). The L/D ratio is first calculated for the distribution zone 34. The distribution zone 34 has a first depth from the boundary 35c of the analysis zone 35 to the horizontal bottom surface 34c of the distribution zone 34 which is equal to the calculated inflow conduit 7 inner diameter (i.e., 4 mm) plus 1 mm. This depth continues from the second end 22 of the inflow conduit 7 for a distance equal to the inner diameter of the inflow conduit 7 (i.e., 5 mm). The L/D_1 of the first segment S1 is the length L_{S1} of the first segment S1, which is 5 mm, divided by the overall depth of the first segment S1, which is the analysis depth of 1 mm plus 1 mm plus the inflow conduit inner diameter of 5 mm, which equals 5/7 or 0.71.

The distribution zone bottom is now slanted, preferably at 60 degrees until it intersects with the analysis zone bottom. Knowing that the intersection angle between the bottom surface 34c of the distribution zone 34 and the bottom end 35 of the analysis zone is 60°, the slanted portion of the second segment S2 will intersect the bottom of the analysis zone point 86 after 3.5 mm from point 84, where the largest depth along 84 plus largest depth along 86 both divided by 2, can be calculated as $(7+1)/2=4$ mm. Therefore L/D_2 of the second segment S2 is the length L_{S2} of the second segment, which is 3.5 mm, divided by the calculated depth of the second segment S2, which equals 3.5/4 or 0.87.

The third segment S3 has a depth equal only to the depth of the analysis zone 35 (i.e., 1 mm) and a length L_{S3} corresponding the remaining length for the original calculated 25 mm of the longitudinal surface of the analysis zone 35 (i.e., 25 mm-8.5 mm=16.5 mm). The L/D_3 of the third segment S3 is therefore 16.5.

The fourth segment S4 to calculate to design this sample housing 30 corresponds to the ventilation zone 36. The length of the fourth segment S4 (i.e., the length of the ventilation zone 36) is unknown and is determined by its conformance to the rule that the sum of L/D of all segments is greater than 25. For example, if the ventilation zone is 2 mm in length with a depth of 0.2 mm, this would result in an L/D_4 value of 10, and thus a summation of the L/D ratio

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of all of the segments of the sample S (i.e., $0.71+0.87+16.5+10$) would be 28. As this sum is greater than 25, it is clear that a ventilation zone **36** length of 2 mm would be acceptable for this example. In this Example, the ventilation zone **36** length was chosen to be 5 mm and, as such, sum $(L/D)=43$ which is within the range of all economical possibilities (i.e., $25<\text{sum}(L/D)<50$).

As such, it is shown that the length of each segment can be as small as measurable and still provide the necessary output. Smaller segments are desirable for the designer to conform to the criteria that no individual segment L/D can decrease in value in the direction from the inflow conduit **7** to the gas coupler **2**.

Considering the requisite mass ratio of between 9 to 12, the sample chamber **3** of this Example has a housing **30** of a mass of approximately 57 g and a cover plate with a mass of approximately 9.4 g, for retrieval and chilling of a 6 g sample (i.e., mass ratio of 11.1).

Example 1 represents a particularly preferred embodiment of the invention.

Example 2

A sample housing **30** of aluminum is machined according to FIGS. 1-6. The analysis zone **35** has a uniform depth D_A of 0.8 mm above the distribution zone **34**. The length L_A of the analysis zone **35** is chosen to be 32 mm to accommodate 4 analysis spots.

The width W_A of the analysis zone **35** is similarly selected to be 10 mm with a slight taper in cross section, such that the maximum cross-sectional area (i.e., depth times width) is toward the immersion direction I. Thus, the largest cross-sectional area of the analysis zone **35**, which is located in the immersion direction I and more particularly proximate the inlet conduit **7**, is 8 mm^2 (i.e., depth of 0.8 mm multiplied by width of 10 mm). Because the cross-sectional area of the inflow conduit **7** is between 0.5 and 2 times the cross-sectional area of the analysis zone **35**, the cross-sectional area of the inflow conduit **7** can be between 4 and 16 mm^2 . The inflow conduit **7** is a quartz tube. Therefore, the inner diameter of the inflow conduit **7** is between 2.5 and 5.1 mm. For this example, the inflow conduit **7** has an inner diameter of 4 mm (i.e., cross-sectional area of 12.6 mm^2). Because the cross-sectional area of the inflow conduit **7** is between 0.20 and 0.70 times the largest cross-sectional area of the distribution zone **34**, the cross-sectional area of the distribution zone **34**, with rounding, can be between approximately 18 and 63 mm^2 . The second portion of the bottom surface **34c** of the distribution zone **34** intersects the bottom end **35b** of the analysis zone **35** at an angle of 60° .

The cross-sectional area of the ventilation zone **36**, at the largest area, is 0.8 mm^2 . Since the width of the analysis zone **35** is 10 mm, the average depth D_V of the ventilation zone **36** is 0.2 mm.

The analysis portion of a sample S created using the housing **30** of Example 1 thus has a length of 32 mm and a thickness of 0.8 mm (i.e., corresponding to the analysis zone **35** dimensions). The L/D ratio is first calculated for the distribution zone **34**. The distribution zone **34** has a first depth from the boundary **35c** of the analysis zone **35** to the horizontal bottom surface **34c** of the distribution zone **34** which is equal to the calculated inflow conduit **7** inner diameter (i.e., 4 mm) plus 1 mm. This depth continues from the second end **22** of the inflow conduit **7** for a distance equal to the inner diameter of the inflow conduit **7** (i.e., 4 mm), however other distances are possible. The L/D_1 of the first segment **S1** is the length L_{S1} of the first segment **S1**, which

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is 4 mm, divided by the overall depth of the first segment **S1**, which is the depth of 0.8 mm plus 1 mm plus the inflow conduit inner diameter of 4 mm, which equals $4/5.8$ or 0.69.

The distribution zone bottom is now slanted, preferably at 60 degrees until it intersects with the analysis zone bottom. Knowing that the intersection angle between the bottom surface **34c** of the distribution zone **34** and the bottom end **35** of the analysis zone is 60° , the slanted portion of the second segment **S2** will intersect the bottom of the analysis zone at line **86** a distance of 2.9 mm from line **84**, where the largest depth along **84** plus largest depth along **86** both divided by 2 can be calculated as $(5.8+0.8)/2=3.3$. Therefore L/D_2 of the second segment **S2** is the length L_{S2} of the second segment, which is 2.9 mm, divided by the overall depth of the second segment **S2**, which equals $2.9/3.3$ or 0.88.

The third segment **S3** has a depth equal only to the depth of the analysis zone **35** (i.e., 2 mm) and a length L_{S3} corresponding the remaining length for the original calculated 32 mm of the longitudinal surface of the analysis zone **35** (i.e., $32\text{ mm}-6.9\text{ mm}=25.1\text{ mm}$). The L/D_3 of the third segment **S3** is therefore 31.4.

The fourth segment **S4** to calculate to design this sample housing **30** corresponds to the ventilation zone **36**. The length of the fourth segment **S4** (i.e., the length of the ventilation zone **36**) is unknown and is determined by its conformance to the rule that the sum of L/D of all segments is greater than 25. For example, if the ventilation zone is 2 mm in length with a depth of 0.2 mm, this would result in a L/D_4 value of 10, and thus a summation of the L/D ratio of all of the segments of the sample S (i.e., $0.69+0.88+31.4+10$) would be 43 which is within the range of all economical preferences. (i.e., $25<\text{sum}(L/D)<50$).

As such, it is shown that the length of each segment can be as small as measurable and still provide the necessary output. Smaller segments are desirable for the designer to conform to the criteria that no individual segment L/D can decrease in value in the direction from the inflow conduit **7** to the gas coupler **2**.

One skilled in the art can understand from the above Examples that all dimensions of the metal sample S can therefore be calculated based on the dimensions of the housing **30**.

The probe **10**, and particularly the sample chamber **3**, could be used in all sampling applications where normal conventional sampling devices of the prior art are employed. The advantage of the present invention is best understood in light of hot metal processes that are very fast and overtreatment of metal and/or over processing of a heat can result in high additional expense in terms of time and materials that could have been avoided by a readily available metal chemistry at the process location.

The invention provides a solution to the shortcomings of the prior art by providing a solidified sample of hot metal fulfilling the following requirements:

- a metal sample that is analysed on an optical emission spectrometer,
- a solid metal sample without gas porosity and slag entrapment,
- a flat, as-retrieved analysis surface without fluid flow lines fixing the distance from the surface to the anode of the OES,
- a sample analysis surface free of oxidation,
- a homogeneous metal sample of a maximum thickness perpendicular to the analysis plane to eliminate areas of metal and non-metallic segregation,

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a sample analytical surface spanning approximately 10 mm×30 mm and thereby providing sufficient surface area to obtain at least 2, preferably 4 sparks, and
 a sample surface that lies in the same plane as the sample housing into which the sampled metal was chilled, such that the plane of the sample analytical surface is extended without interruption in both surface directions by the sample housing 30 (namely the ridge 39) with a variation of less than 0.1 mm.

It will be appreciated by those skilled in the art that changes could be made to the embodiments described above without departing from the broad inventive concept thereof. It is understood, therefore, that this invention is not limited to the particular embodiments disclosed, but it is intended to cover modifications within the spirit and scope of the invention as defined by the appended claims.

What is claimed is:

1. A sampler for taking samples from a molten metal bath, the sampler comprising:

a carrier tube having an immersion end;
 a sample chamber assembly arranged on the immersion end of the carrier tube, the sample chamber assembly comprising a cover plate and a housing, characterized in that the housing includes:
 an immersion end having a first opening for an inflow conduit and an opposing end having a second opening for a gas coupler; and
 a first face extending between the immersion end and the opposing end,

wherein the cover plate and the housing are configured to be assembled together to form a sample cavity including a distribution zone, an analysis zone and a ventilation zone, a portion of the analysis zone overlying the distribution zone which is in direct flow communication with the first opening and configured to receive molten iron from the inflow conduit,

wherein a depth of the analysis zone is 0.5 mm to 1.5 mm, wherein the sample cavity has dimensions of length, width and depth, wherein the length dimension is along the inflow direction of the molten metal, the depth dimension is perpendicular to the length dimension, and the width dimension is perpendicular to the both the depth dimension and the length dimension,

wherein the distribution zone, the analysis zone and the ventilation zone are structured as a plurality of contiguous segments, each segment having a length to depth ratio, the length to depth ratios of the segments successively increasing as the distance from the first opening increases,

wherein the assembled cover plate and housing are configured to chill the molten iron received therein to a solidified white structure metal sample, such that an analysis surface of the solidified white structure metal sample lies in a first plane, and

wherein the first and second openings are spaced apart from the first plane.

2. The sampler according to claim 1, characterized in that the sample cavity and the first and second openings are aligned along a common longitudinal axis.

3. The sampler according to claim 1, characterized in that the analysis zone, distribution zone and ventilation zone are structured as a plurality of contiguous segments, each segment having a length to depth ratio, a sum of the length to depth ratios of the plurality of segments being greater than

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4. The sampler according to claim 1, characterized in that there are no increases in the width dimension of at least a portion of the sample cavity in a flow direction of the molten iron which extends from the end of the distribution zone toward the second opening.

5. The sampler according to claim 1, characterized in that a total length of the analysis zone and the ventilation zone is between 20 and 50 mm.

6. The sampler according to claim 1, characterized in that the analysis zone has a uniform depth above the distribution zone.

7. The sampler according to claim 1, characterized in that a cross-sectional area of at least a portion of the analysis zone gradually tapers in the flow direction of the molten iron.

8. The sampler according to claim 1, characterized in that a cross-sectional area of the ventilation zone gradually tapers in the flow direction of the molten iron.

9. The sampler according to claim 1, characterized in that a ratio of a mass of the sample chamber to a mass of the metal received within the sample collection volume is 9 to 12.

10. The sampler according to claim 1, characterized in that the cover plate accounts for 10 to 20 percent of the mass of the sample chamber.

11. The sampler according to claim 1, characterized in that a cross-sectional area of the inflow conduit is between 0.25 and 0.5 times of a cross-sectional area of the distribution zone.

12. The sampler according to claim 1, characterized in that a bottom surface of the distribution zone intersects a closed bottom end of the analysis zone at an angle between 40 and 90°.

13. The sampler according to claim 1, characterized in that the cover plate includes a sealing member configured to provide a substantially gas tight seal between the cover plate and the housing.

14. The sampler according to claim 1, characterized in that the cover plate is secured to the housing by a metal clamp to form the sample chamber.

15. The sampler according to claim 1, characterized in that the first and second openings are the only openings formed in the sample cavity, an end of the inflow conduit being secured within the first opening and an end of the gas coupler being secured within the second opening.

16. The sampler according to claim 1, characterized in that a cross-sectional area of the inflow conduit is between 0.5 and 2 times of a cross-sectional area of the analysis zone.

17. The sampler according to claim 1, characterized in that the inflow conduit, the distribution zone, the analysis zone, the ventilation zone and the gas coupler are sequentially arranged in this order in the flow direction of the molten iron.

18. The sampler according to claim 1, characterized in that the first face of the housing includes a ridge protruding therefrom and surrounding the ventilation zone, the analysis zone and the distribution zone.

19. The sampler according to claim 1, characterized in that when the cover plate and the housing are assembled together, the cover plate sits flush against the ridge of the housing along the first plane.